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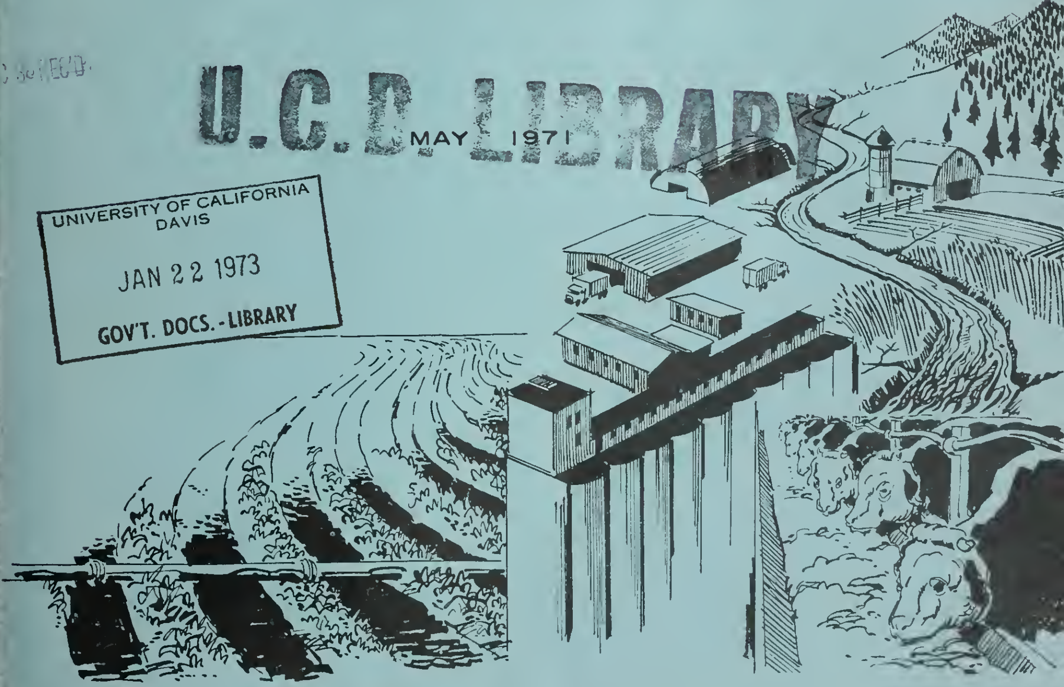
BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE

SAN JOAQUIN VALLEY, CALIFORNIA

NUTRIENTS FROM TILE DRAINAGE SYSTEMS

MAY 1971



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CALIFORNIA DEPARTMENT OF WATER RESOURCES

BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE SAN JOAQUIN VALLEY, CALIFORNIA

The Bio-Engineering Aspects of Agricultural Drainage reports describe the results of a unique interagency study of the occurrence of nitrogen and nitrogen removal treatment of subsurface agricultural wastewaters of the San Joaquin Valley, California.

The three principal agencies involved in the study are the Water Quality Office of the Environmental Protection Agency, the United States Bureau of Reclamation, and the California Department of Water Resources.

Inquiries pertaining to the Bio-Engineering Aspects of Agricultural Drainage reports should be directed to the author agency, but may be directed to any one of the three principal agencies.

THE REPORTS

It is planned that a series of twelve reports will be issued describing the results of the interagency study.

There will be a summary report covering all phases of the study.

A group of four reports will be prepared on the phase of the study related to predictions of subsurface agricultural wastewater quality -- one report by each of the three agencies, and a summary of the three reports.

Another group of four reports will be prepared on the treatment methods studied and on the biostimulatory testing of the treatment plant effluent. There will be three basic reports and a summary of the three reports. This report, "NUTRIENTS FROM TILE DRAIN SYSTEMS", is one of the three basic reports of this group.

The other three planned reports will cover (1) techniques to reduce nitrogen during transport or storage, (2) possibilities for reducing nitrogen on the farm, and (3) desalination of subsurface agricultural wastewaters.

BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE
SAN JOAQUIN VALLEY, CALIFORNIA

NUTRIENTS FROM TILE DRAINAGE SYSTEMS

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REVIEW NOTICE

This report has been reviewed by the Water Quality Office, Environmental Protection Agency and the U. S. Bureau of Reclamation, and has been approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Water Quality Office, Environmental Protection Agency, or the U. S. Bureau of Reclamation.

The mention of trade names or commercial products does not constitute endorsement or recommendation for use by either of the two federal agencies or the California Department of Water Resources.

ABSTRACT

Tile drainage systems of the San Joaquin Valley were monitored for nutrients (nitrogen and phosphorus). The objectives were to determine: (1) the average nutrient concentrations in tile drainage, (2) the magnitudes of annual, areal and seasonal variability of nutrients and discharges, (3) if a possible correlation exists between nutrients and agricultural practices, and (4) if existing soil conditions influence nutrient concentrations and flows. From this information it will be possible to determine the algal growth potential (AGP) of the waste, and the degree of treatment required for removal of AGP.

Average discharges, nutrient concentrations and total dissolved solids were calculated for different years, months, physiographic positions, soil series, and valleywide areas of interest. Average nutrient concentrations in the composited drainage from the Valley were found to be 19.3 mg/l for nitrate-nitrogen, 0.09 mg/l for phosphate-phosphorus, and 3,625 mg/l for total dissolved solids; average discharge was 1.4 ac-ft/ac. Nutrient levels in the composited drainage did not change appreciably from year to year. Variability of nutrients was observed for different seasons; a twofold decrease in nutrients was attributed to dilution by irrigation and denitrification. Nitrogen was three times more concentrated in drainage from one out of four major tiled areas investigated. The high nitrogen levels were attributed more to indigenous concentrations in certain alluvial fan soils and their parent materials than fertilization. Low nitrogen levels found in drainage from basin soils were believed caused by denitrification. Phosphorus was seven times higher in the drainage from the southernmost area than the other areas investigated. These extraordinarily high levels (0.69 mg/l) were attributed to indigenous concentrations in certain soils made available by anaerobic soil conditions. High discharge in the northernmost area (2.3 ac-ft/ac) was believed to be caused by rapid lateral hydraulic conductivity and surrounding irrigation influence.

This report was prepared by the California Department of Water Resources in conjunction with other agricultural wastewater studies which were conducted by the United States Bureau of Reclamation and the Water Quality Office of the Environmental Protection Agency.

Key words: agricultural waste, tile drainage, nutrients, composited drainage, nutrient variability, indigenous concentrations.

BACKGROUND

This report is one of a series which presents the findings of intensive interagency investigations of practical means to control the nitrate concentration in subsurface agricultural wastewater prior to its discharge into other water. The primary participants in the program are the Water Quality Office of the Environmental Protection Agency, the United States Bureau of Reclamation, and the California Department of Water Resources, but several other agencies also are cooperating in the program. These three agencies initiated the program because they are responsible for providing a system for disposing of subsurface agricultural wastewater from the San Joaquin Valley of California and protecting water quality in California's water bodies. Other agencies cooperated in the program by providing particular knowledge pertaining to specific parts of the overall task.

The need to ultimately provide subsurface drainage for large areas of agricultural land in the western and southern San Joaquin Valley has been recognized for some time. In 1954, the Bureau of Reclamation included a drain in its feasibility report of the San Luis Unit. In 1957, the California Department of Water Resources initiated an investigation to assess the extent of salinity and high ground water problems and to develop plans for drainage and export facilities. The Burns-Porter Act, in 1960, authorized San Joaquin Valley drainage facilities as a part of the state water facilities.

The authorizing legislation for the San Luis Unit of the Bureau of Reclamation's Central Valley Project, Public Law 86-488, passed in June 1960, included drainage facilities to serve project lands. This Act required that the Secretary of Interior either provide for constructing the San Luis Drain to the Delta or receive satisfactory assurance that the State of California would provide a master drain for the San Joaquin Valley that would adequately serve the San Luis Unit.

Investigations by the Bureau of Reclamation and the Department of Water Resources revealed that serious drainage problems already exist and that areas requiring subsurface drainage would probably exceed one million acres by the year 2020. Disposal of the drainage into the Sacramento-San Joaquin Delta near Antioch, California, was found to be the least costly alternative plan.

Preliminary data indicated the drainage water would be relatively high in nitrogen. The then Federal Water Quality Administration conducted a study to determine the effect of discharging such drainage water on the quality of water in the San Francisco Bay and Delta. Upon completion of this study in 1967, the Administration's report concluded that the nitrogen content of untreated drainage waters could have significant adverse effects upon the fish and recreation values of the receiving waters. The report recommended a three-year research program to establish the economic feasibility of nitrate-nitrogen removal.

As a consequence, the three agencies formed the Interagency Agricultural Wastewater Study Group and developed a three-year cooperative research program which assigned specific areas of responsibility to each of the agencies. The scope of the investigation included an inventory of nitrogen conditions in the potential drainage areas, possible control of nitrates at the source, prediction of drainage quality, changes in nitrogen in transit, and methods of nitrogen removal from drain waters including biological-chemical processes and desalination.

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SECTION I

SUMMARY AND CONCLUSIONS

Summary

Tile drainage systems in the San Joaquin Valley were intensively monitored from 1966 through 1968. This report emphasizes nutrient data collected during that period. Nutrient and soils data are also presented from investigations conducted prior to 1966, from other investigations during the 1966 through 1968 period, and from a continuing monitoring program which was initiated in 1969.

Average Nitrogen (nitrate-nitrogen) Concentrations

The nitrate ion (NO_3) is the dominant nitrogen constituent found in San Joaquin Valley tile drainage. The combined amounts of ammonium (NH_4), nitrite (NO_2), and organic nitrogen rarely exceed 1.0 milligram per liter (mg/l) in the drainage regardless of the total levels found. All discussions of nitrogen that follow in this report will be limited to nitrate-nitrogen.

Nitrogen averaged 19.3 mg/l in the combined drainage from tile systems monitored on a regular basis from 1962 through 1969. During 1968, forty-two tile systems were monitored weekly for a full year in all of the major tiled areas. During the same period a number of "isolated" and "satellite" tile systems were also sampled monthly during most of the year. The composite drainage from all of these systems averaged 20 mg/l.

Variations of Nitrogen Concentrations

The average nitrogen concentration remained relatively constant from year to year during the more intensive investigations. During 1967 and 1968, the annual averages were 18.6 mg/l and 19.9 mg/l, respectively. The annual average for 1969 (19.4 mg/l) was only slightly less than that of 1968.

The greatest long-term change in average nitrogen levels appeared to occur between 1962 and 1966 when the concentration decreased from 25.1 mg/l to 18.6 mg/l, respectively. This change occurred primarily because a larger number of low nitrogen level tile systems were sampled in 1966 that were not included in the earlier investigations.

Long-term variability of nitrogen was, however, apparent in the drainage from individual tile systems. Though the overall percentage of change was small, the absolute changes were on the order of 6 to 8 mg/l over a decade. This degree of variability is due primarily to changes in agricultural management which includes the type of crop grown and the irrigation frequency and duration.

Nitrogen accumulation in the subsoil due to fertilization or leaching of nitrogen from the soil due to irrigation was not apparent in the drainage observed from the individual systems studied over several years. High concentrations of nitrogen are still found in the drainage from fields tiled since 1950 and irrigated for forty or more years in the San Joaquin Valley.

Nitrogen also varies on a short-term basis in drainage from individual systems. Hourly, daily, and weekly variability was studied for several drainage systems. During a 24-hour sampling period, nitrogen ranged from 4 mg/l to 12 mg/l in a particular drain that had a fixed discharge. The standard deviation was 1.8 mg/l. Another system, considered rather typical of many along the west side of the Valley, had hourly concentrations that ranged from 92 mg/l to 182 mg/l and a standard deviation of 19.8 mg/l. For the most part these hourly variations were comparable to those observed from week to week during the tile monitoring investigations. These short-term changes of nitrogen in drainage can be attributed to dynamic moisture conditions -- caused by varying irrigation patterns and soil texture combinations.

Nitrogen varies monthly in drainage composited from the San Joaquin Valley tile systems. Monthly changes were gradual but rather consistent from year to year. Two-fold seasonal variations were observed; nitrogen concentrations in the composited drainage were about 34 mg/l in March and 14 mg/l in August.

Nitrogen concentrations vary in drainage from certain geographical areas in the San Joaquin Valley. Drainage was composited separately for the four heavily tiled areas in the Valley. The systems sampled represent about one-third of present total tiled acreage. These major tiled areas are: two northern areas (Byron to Westley and Westley to Gustine), the central area (Gustine to Mendota) and the southern area (Tulare lakebed). Nitrogen concentrations averaged 33 mg/l in drainage from the central area, which was more than three times higher than the drainage from either of the two northern areas or the southern area. At first these variations were thought to be due to differences in fertilizer application. Immediate or prolonged fertilization had no observable effect upon nitrogen concentrations in the tile drainage. Agricultural records collected by the Department show that many tile systems were fertilized heavily over the years but discharged effluent relatively low in nitrogen.

A study of agricultural practices revealed that irrigation was the only agricultural practice that greatly influenced changes in nitrogen concentrations. Immediate decreases in nitrogen levels were observed in drainage from many tiled rice fields during flooding. Drainage from one large tile system decreased from 63 mg/l in the winter to 7 mg/l in the summer. Nitrogen concentrations fluctuated in drainage from other tiled crops during irrigation but generally decreased during the summer months. Denitrification and dilution are highly suspected as the reasons for summer decreases in nitrogen concentrations.

Levels and Sources

The level of nitrogen concentrations was found to be most related to location and type of soil (physiographic position and soil series). Drainage from tile systems occupying recent or older alluvial fans generally was higher in nitrogen than drainage from tile systems located in basin or basin rim physiographic positions. Nitrogen concentrations, however, were much higher in drainage from tile systems located in alluvial fans of the central area than drainage from systems located in similar fans of the two northern areas. These differences led to a close look at the individual soil series as a source of nitrogen in the drainage.

The highest concentrations of nitrogen (about 45 mg/l) occurred in drainage from the Panoche family group (Panhill, Panoche, and Lost Hills soil series) of the central area. Nitrogen levels were roughly 10.0 mg/l in drainage from the Sorrento family of soils (Sorrento, Rincon, and Ambrose soil series), and other nonrelated basin and basin rim soils.

Soil investigations were conducted by the Department at 44 sites along the west side of the San Joaquin Valley. Virgin as well as irrigated sites were sought to evaluate the variation in concentrations of nitrogen in the soil profiles. Nitrate-nitrogen was found in all virgin soil profiles sampled. The highest concentrations (saturation extracts) were found in soil samples taken from virgin profiles of Panoche and related soil series in the central area. All virgin sites of Panoche and related soils averaged about 97 mg/l in the 3- to 10-foot tile zone (ranging from 8 to 234 mg/l).

Deep boring investigations conducted by soil scientists of the Agricultural Research Service (ARS) also revealed high levels of nitrogen (up to 225 mg/l) in Panoche soil profiles along the west side of the San Joaquin Valley. Further investigations by ARS showed very high concentrations of nitrogen in parent materials of the Panoche soils. Average nitrogen concentrations of the various parent material strata ranged up to 2,000 mg/l in 1:1 soil-water extracts.

Irrigated sites of different soil series contained less nitrogen in the soil than virgin sites of the same series. Eleven irrigated sites of Panoche soils averaged 37 mg/l -- 60 mg/l less than the virgin Panoche soils. Nitrogen concentrations in samples collected from five irrigated Panoche sites (25 borings) in the Federal San Luis Unit Service Area (SLUSA) by the United States Bureau of Reclamation (USBR) averaged 19 mg/l overall and ranged from 5 to 35 mg/l between sites. Although these concentrations were somewhat lower than those found by DWR, one site of the Lost Hills series (which is closely related to the Panoche series) had the highest average concentration found (109 mg/l).

Alluvial fan soils of the two northern areas appear to contain less nitrogen than those of the central area. Much lower concentrations were found in samples collected from the Sorrento and related soil series. Nitrogen levels averaged 25 mg/l and ranged from 2 to 59 mg/l for the five sites sampled.

All of the basin rim soils investigated were irrigated. Average nitrate-nitrogen levels ranged from 1 mg/l to 171 mg/l and averaged about 37 mg/l. Out of the eight basin rim sites sampled, two contained high levels of nitrogen (more than 100 mg/l). The other six were low (less than 5 mg/l). Higher concentrations were found by USBR in some of the irrigated soils of the Federal San Luis Unit Service Area. The Oxalis series, which comprises the major portion of the basin rim soils in the area, averaged 64 mg/l for the four sites investigated and ranged from 5 to 206 mg/l between sites. The other basin rim soils in the area averaged less than 10 mg/l nitrate-nitrogen for the 3- to 10-foot tile zone.

Comparisons were made between the nitrogen observed in tile drainage and that found in field moisture samples (porous cups) and soil samples (saturation extracts) collected from the same tiled fields. The comparisons showed that in three out of four cases nitrogen was higher in the field moisture samples than in tile drainage from the same field. Saturation extracts prepared from soil samples were, however, about 30 to 40 percent lower than the average concentrations found in the tile drainage.

At this time, predictions of nitrogen from future-drained areas based on nitrogen in soil samples or field moisture samples can be made only with additional field study and extensive correlation to existing tile drainage.

In summary, the one thing that can be said about tile drainage is that its nitrogen content will vary greatly between certain areas and also during the seasons. The magnitude of variability depends basically upon three things: (1) the particular kind of soil a tile system is associated with and its physical location, (2) the irrigation pattern, and (3) to a lesser extent, the type of crop being grown. Although nitrogen levels from individual systems cannot be accurately predicted from year to year, the Department is reasonably certain that nitrogen levels in future drainage can be predicted from the composite drainage of existing tile systems in the San Joaquin Valley.

Phosphorus (phosphate-phosphorus)

Phosphate (orthophosphate) is the major phosphorous constituent found in tile drainage of the San Joaquin Valley. Very low concentrations of organic phosphorus were found because of the low organic content of the tile drainage. Laboratory analyses revealed that concentrations of orthophosphate in tile drainage were essentially the same as total plus organic phosphorus. For this reason emphasis in this report is given to orthophosphate, which is referred to as phosphorus.

Phosphorous concentrations averaged 0.09 mg/l in drainage composited from valley tile systems during 1962 to 1969.

According to the available data, there are no indications of long-term changes in phosphorus. Phosphorus from the Tulare Lake area averaged 0.69 mg/l -- seven times higher than drainage from either of the two northern areas or the central area. Concentrations averaged less than 0.1 mg/l in the composited drainage from any one of these three areas.

The high levels of phosphorus in drainage from the Tulare Lake area are suspected to be due to unusual source materials contained in the soils. Analyses of the soils do not indicate high concentrations of phosphorus, but there is an abundance of phosphorous-bearing fresh water shells in the soil profiles from that area. It is suspected that anaerobic conditions exist in the saturated subsoils of the lakebed which create an environment conducive for the release of phosphorus from the shells and their related organic remains.

Seasonal variations of phosphorus in the composited tile drainage were comparable to that of nitrogen; that is, summertime decreases were attributed to dilution in the soil caused by irrigation. The highest average concentrations were observed in January (about 0.2 mg/l); the lowest occurred in July (about 0.09 mg/l).

In conclusion, the present composite drainage from the major tiled areas investigated is not indicative of phosphorous concentrations in future valleywide drainage. Phosphorous concentrations could increase as a result of drainage from other lakebed areas having soils similar to that in the Tulare Lake area. Based on predicted drain flows for the year 2020, average concentrations in the drainage would be 0.23 mg/l.

Total Dissolved Solids

Total dissolved solids (TDS) averaged 3,625 mg/l in the combined valley drainage for 1962 to 1969. Long-term changes between years were very small; TDS averaged 3,100 mg/l for 1967, 3,200 mg/l for 1968 and 3,550 for 1969. Higher average concentrations were observed for drainage composited during the earlier studies when only a few tile systems from the Gustine-Mendota area were investigated.

TDS concentrations, however, did vary in drainage from individual tile systems. The levels ranged from 1,320 mg/l to 14,600 mg/l for intensively monitored tile systems. A few isolated tile drains were found to be much higher in TDS; for example, one experimental tile system exceeded 100,000 mg/l at the lowest flows.

Seasonal and areal variability of TDS was great for drainage composited from the major tiled areas. TDS averaged about 3,500 mg/l in the winter and decreased to about 2,500 mg/l during the summer.

Drainage from the central area (4,130 mg/l) and southern area (3,760 mg/l) was much higher in TDS than the drainage from tile systems located in the two northern areas. Drainage from the Byron to Westley area averaged 2,170 mg/l -- the Westley to Gustine area averaged 2,740 mg/l.

TDS concentrations have been predicted to decrease significantly in future drainage from the San Joaquin Valley. Although long-time changes were not observed in the data available during this investigation, it is believed that a decrease in TDS would be inevitable if the existing monitoring program was continued for a longer period.

Discharges

The average annual tile discharge from 1966 through 1969 was 1.4 acre-feet per acre (ac-ft/ac) from the tiled areas studied.

Long-term changes in the average tile discharge were not observed during the more intensive investigations. This relatively high discharge figure can possibly be attributed to the fact that there is no way of knowing exactly how many acres are actually drained by a given tile system. Land adjacent to tiled fields or lying upslope some distance from a tiled area is often drained by the tile system. After adjoining fields are tiled, it is expected that the average annual discharge would decrease significantly.

The average monthly discharge from valley tile systems ranged from 0.05 ac-ft/ac in the winter months (December and January) to 0.2 ac-ft/ac during July.

Flows from individual tile drains differed widely. Total annual discharge ranged from a low of 0.3 ac-ft/ac to a high of 17.3 ac-ft/ac for tile systems investigated in 1968. In 1968 it appears that about 14 percent of the tile systems investigated discharged more water than was applied for irrigation, assuming an average application rate of 3.0 ac-ft/ac/yr.

Tile systems in the Byron to Westley area discharged an average of 2.3 ac-ft/ac/yr for a two-year period, which was twice that discharged from the Gustine to Mendota area. Discharges from the Westley to Gustine area (0.69 ac-ft/ac/yr) was close to that observed from tile systems in the Tulare Lake area (0.57 ac-ft/ac/yr).

Although tile discharge varies greatly between tile systems and major tiled areas depending upon soil conditions and irrigation, the average discharge from a large area of drainage systems can be expected to remain rather constant from one year to the next.

Conclusions

1. Nutrient (nitrogen and phosphorous) concentrations in tile drainage composited from the San Joaquin Valley can be expected to be close to the values previously predicted by the Department of Water Resources in Appendix D, Bulletin No. 127, "Waste Water Quality, Treatment, and Disposal", April 1969.

2. On the basis of observations made during this investigation, nutrient concentrations in the tile drainage from the San Joaquin Valley are not expected to change appreciably within the next 50 years.

3. Nutrient concentrations and total dissolved solids in composited drainage can be expected to vary inversely with the seasonal application of irrigation water.

4. Dilution and denitrification are highly suspect as the reasons for decreases in concentration of nutrients and TDS in tile drainage during the summer.

5. Denitrification is believed to be the main reason for low nitrogen concentrations in tile drainage from the basin rim and basin soils.

6. The areal variability of nitrogen found in the tile drainage is more dependent upon the particular soil series and the physiographic position of the tile systems than on agricultural influence.

7. The relative concentrations of nitrogen in tile drainage from future tiled areas can possibly be predicted on the basis of current tile drainage data, along with a representative soil-nitrogen sampling program.

8. High phosphorous concentrations in tile drainage from certain areas is attributed to indigenous quantities in the soil made available by anaerobic soil conditions.

9. The quantity of drainage from a given area depends more on the interrelationships of physiographic position, soil stratigraphy and texture, and irrigation than on irrigation alone.

SECTION II

INTRODUCTION

This report describes the nutrient monitoring investigations conducted over a period of ten years, from 1959 through 1969, the greatest emphasis being placed on the more intensive investigations conducted recently.

Intensive investigations of nutrients in San Joaquin Valley agricultural subsurface (tile) drainage were undertaken from May 1959 through June 1969, as part of the San Joaquin Valley Drainage Investigation (1).

Area of Investigation

Drainage problems have existed for some time in many areas within the trough of the San Joaquin River Basin and the Tulare Lake Basin. However, during the last two decades severe high water table conditions have increased in many areas where subsoil permeability is restricted and irrigation has been intensive. Existing high salt concentrations in subsurface water have caused extensive damage to crops and rendered large acreages nonproductive. The use of subsurface drains as a practical means of alleviating high water table conditions was initiated in the San Joaquin Valley 20 years ago, following many years of successful operation in the Imperial Valley.

Now more than 34,000 acres are directly subjected to tile drainage within the San Joaquin Valley; a much larger acreage may actually be benefited because tile systems intercept lateral movement of subsurface waters from adjacent and upslope areas. Installation figures obtained from the U. S. Department of Agriculture indicate that new tile systems have been installed at an average rate of about 200,000 linear feet per year in the valley areas. In addition, a massive network of tile drains covering 300,000 acres has been planned by the Westlands Water District for the Federal San Luis Unit Service Area in western Fresno and Kings Counties. Although drainage problems exist to some extent in every county on the valley floor, tile installation has progressed most rapidly in portions of San Joaquin, Stanislaus, Merced, Fresno, and Kings Counties. Tile drains in San Joaquin County are situated along the west side, between the towns of Byron and Westley; in Stanislaus County, between Westley and the town of Gustine; in Merced County and northwest Fresno County, between the towns of Gustine and Mendota; and in Kings County, west of the City of Corcoran, on the northeastern shore of the old Tulare lakebed.

These major tiled areas are geographically separated on the valley floor as shown in Figure 1 and are differentiated from one another in this report by the towns named above. When deemed appropriate, tiled areas are referred to as the northern, central, and southern areas, which correspond to the Byron-Gustine (includes both northernmost tiled areas), Gustine-Mendota, and Tulare Lake Basin areas, respectively.

Isolated Tile Systems

A number of isolated tile drainage systems exist throughout the major drainage problem areas and also in several other poorly drained areas, including certain portions along the east side of the Valley at the base of the Sierra Nevada foothills. Most of these systems are isolated, many of them representing localized drainage conditions not particularly representative of the surrounding area.

Objectives

The objectives of the monitoring investigations were to: (1) determine the average nutrient concentrations in tile drainage and the average flows from existing tile drainage systems of the San Joaquin Valley, (2) determine the magnitudes of annual, areal, and seasonal variability of nutrient concentrations and discharges of tile drainage throughout the major tiled areas of the San Joaquin Valley, (3) if possible, correlate observed nutrient concentrations and tile discharges to agricultural practices, and (4) determine whether soil conditions exist that may influence nutrient concentrations or flows of tile drainage systems.

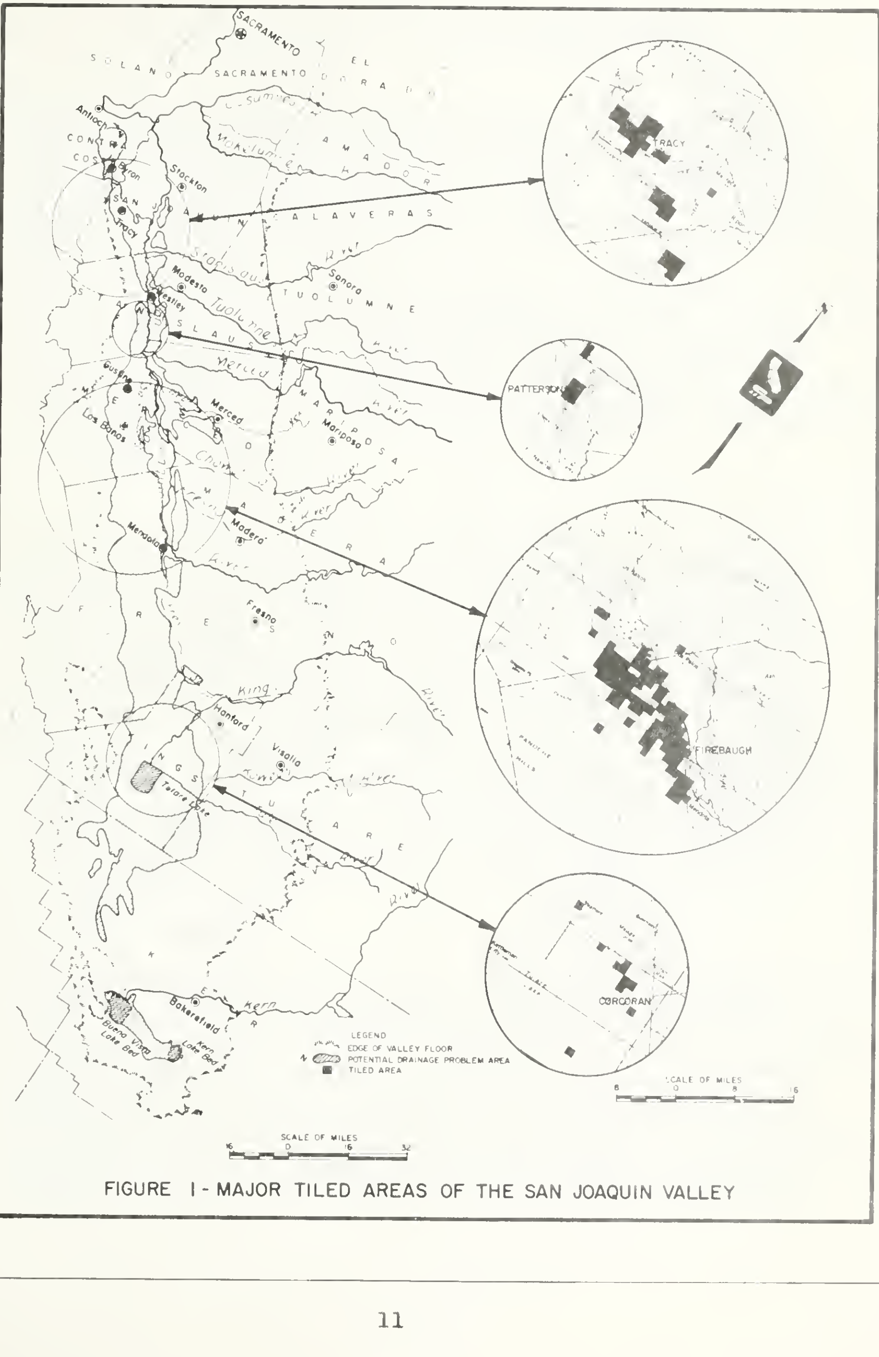

FIGURE 1 - MAJOR TILED AREAS OF THE SAN JOAQUIN VALLEY

SECTION III

TILE DRAINAGE IN THE SAN JOAQUIN VALLEY

Simply stated, a subsurface drainage system consists of a deep open drain or some form of conduit so placed in the soil that it effectively drains subsurface water away from the root zone within a field. Subsurface drains and tile drains are used interchangeably in this report and refer to tile, concrete, plastic, or other pipeline material used as conduit.

Several interrelated factors influence the quantity and quality of tile drainage from different parts of the Valley. These factors are: (1) tile drain design, (2) materials used in construction, (3) effective placement, (4) soil characteristics, (5) agricultural management, (6) precipitation, and (7) age of installation. These factors will be discussed in the subsections that follow.

Historic Background

The first tile drainage systems in the San Joaquin Valley were installed at Kearney Park in Fresno County in 1905. For many years thereafter, very few tile systems were installed elsewhere. The first tile drains along the west side began to appear in the central area near the town of Firebaugh around 1950, following 20 years of successful operation in the Imperial Valley. During the next decade, many systems were installed, not only in the vicinity of Firebaugh but also in the northern and southern areas near the towns of Tracy and Corcoran, respectively. During the last decade more tile systems have been installed nearly every year near Firebaugh and Tracy; the installation of tile systems in other areas has been somewhat sporadic.

Tile Drain Design

Tile drain designs have changed very little from the first known tile system (2) installed near Geneva, New York, in 1835. Considerable work has recently been accomplished on tile drainage theory by many investigators (3), but practical application at this time has been thwarted by efforts to deal economically with variable soil conditions (i.e., stratigraphy, barrier depth and permeability) that exist in west side soils. In some cases the proximity of canals and local physiographic features such as rivers, sloughs, and depressions may be influential in determining the design criteria. However, the cost of construction still plays an important part in determining the final design. Many tile systems are installed in a piecemeal fashion. That is, laterals are added whenever it is economically feasible for a farmer to do so.

In the San Joaquin Valley, two basic tile system designs are generally used: (1) the "interceptor" type, which is a single-line drain placed on the periphery of a field to intercept or reduce lateral movement of water, and (2) the "total relief" type, which consists of a large number of closely spaced laterals (distances vary from 200 to 400 feet) designed to alleviate existing high water table conditions within an entire field. These two types of tile system layouts are illustrated in Figures 2 and 3. Modifications of interceptor type drains have led to the use of other terms, such as "partial relief", which refers to single-line or interceptor drains in which one or two laterals are added to alleviate specific high water table conditions within a field. Distances between laterals in these systems usually exceed 400 feet; 600- to 800-foot distances are common.

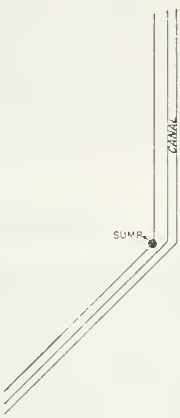

FIGURE 2
INTECEPTOR SYSTEM

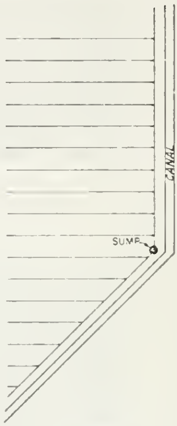

FIGURE 3
TOTAL RELIEF SYSTEM

The term "perimeter interceptor" is applied to fields surrounded by a single-line drain, several of which exist in the area studied.

Various design modifications have been made to adapt tile systems to particular drainage conditions or economic situations. Consequently, many systems cannot be adequately described by the above terminology.

Materials, Construction, and Installation

The sustained performance of a tile system is governed to a great degree by the type of materials used in construction and the methods of installation. Materials used in construction of tile systems in the San Joaquin Valley have been somewhat limited to those products available from local manufacturers. The selection of materials depends mainly on recommendations made by local work unit offices of the Soil

Conservation Service, U. S. Department of Agriculture and tile system contractors; however, final decisions are usually made by individual farmers. The materials, construction, and methods of installation are discussed in the subsections that follow.

Conduit. In the past, the term "tile drain" referred to a drainage system in which red clay tile conduit was used. The term as used locally refers to drainage systems using both concrete and tile. Prior to 1969, concrete pipeline was used almost exclusively in all major tiled areas. Although it usually costs more than red clay tile or plastic conduit, its tongue-and-groove construction resists deformation by the soil more than does the "butt joint" clay tile, which makes it more desirable from a maintenance standpoint.

The use of plastic as conduit is rapidly becoming popular because it is less expensive than concrete pipeline. Several large drainage systems constructed of plastic were installed in the Gustine-Mendota area in 1969 and 1970.

Concrete and tile conduit are segmented, usually in sections whose lengths depend on the diameter. The diameter of conduit to be used is chiefly determined by the size of the drainage system and the expected peak discharge. Plastic conduit is available in several different diameters and usually comes in a more or less continuous roll which is perforated throughout its length. Plastic drains installed recently in the Gustine-Mendota area appear to perform as well as the concrete and clay tile systems.

Filter Materials. To operate satisfactorily, subsurface drainage systems require a filter medium. Sand and gravel placed around the conduit during installation have proven to be quite successful in most major tiled areas. The kind of material and the amount needed seem to be a matter of controversy. Investigation of tile performance by Johnston and Pillsbury (4) has shown that the amount of filter sand has no relationship to the efficiency of drain operation, providing it is no less than 6 and no more than 18 tons per 100 linear feet of conduit.

Soil Conservation Service engineers (5) have reported better results with pea gravel than with graded sand or gravel in tile systems located near Tracy.

Contractors and drainage specialists have reported instances of tile drainage systems which have ceased to function because improper filter materials were used. Fiberglass, used as envelope material in certain experimental plots near Firebaugh, has been found in a deteriorated condition after only a few years in the soil. Inspection of excavated sections of pipeline has often shown that systems installed without filter material and backfilled with soil were "silted in" or were grossly restricted by crop roots. Similar conditions have also been reported for systems which have been improperly vented. Vented systems are those which have vertical sections of pipeline installed at intersections of laterals and the mainline. Cases have been reported where tile system laterals without vents develop a vacuum condition that hastens silting, root growth, and the formation of bacterial sludge. All tile systems monitored during this investigation had sand or gravel filter materials; only a few of the systems monitored were provided with vents.

Installation. The drainage pipelines are usually buried at a predetermined depth and gradient from 5 to 9 feet below the surface of the soil. The specific depth at which pipelines are installed, which is believed by some Soil Conservation Service engineers to be quite critical, varies from one area to another, depending upon soil conditions (texture, stratigraphy, and topography).

Most of the tile systems in the Gustine-Mendota area have been installed at an average depth of about 7 feet. In the Byron-Westley area, many tile systems have been installed at 9-foot depths. One tile contractor claims that deeper drains allow more distance between laterals because of greater drawdown, which permits a lower water table and a more consistent drainage between irrigations.

Tiling operations may differ greatly depending on the type of conduit materials being used. During the installation of concrete pipeline, constant mechanical pressure is applied to the segmented pipe by tiling machines to minimize deformation of the pipe during backfilling and during later subsidence. Some tiling machines employ the use of a television camera to monitor the placement of conduit (center of photograph, Figure 4).

Plastic conduit is now installed with the same basic machinery used to install concrete conduit. The use of hydraulic equipment has been eliminated because alignment is not as critical a factor in the installation of plastic pipe as in the installation of concrete pipe. Therefore, installation time is decreased. New methods of plastic pipeline installation are being developed wherein long strings of conduit are fed into preformed tunnels made by a large subsoiling device.

FIGURE 4. CONCRETE PIPELINE INSTALLATION

Sumps and Outlets

Free-flowing outlets are necessary if water tables are to be maintained at desired levels. Subsurface flow in most tile drains is carried in various laterals to a main collector line located at the low end of a tiled field, and drains into an open ditch or a concrete collector reservoir (sump). A typical tile system layout commonly found on the west side of the Valley is shown in Figure 5.

Sumps are constructed of 7-foot diameter concrete rings which are 3 feet high; when placed one above the other these rings form a sizable reservoir for collection of wastewater. Water levels are usually maintained below the tile outlets by automatically controlled pumps. Tile drainage outlets and level control devices are accessible through a manhole located on top of the sump. A typical sump is shown in Figure 6.

Many tile drains in the northern and central areas have "free" or "gravity" type outlets that empty into open drainage ditches. A few smaller sumps constructed of 3-foot diameter pipeline have been installed near Tracy and in the Tulare Lake area. These pipes are usually placed underground in a horizontal position.

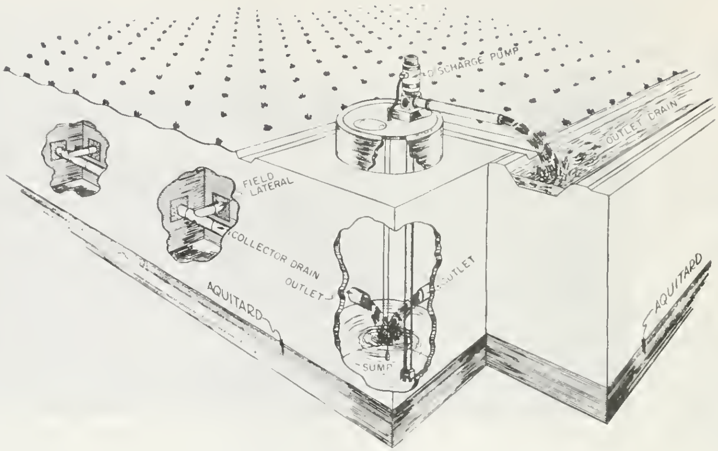

FIGURE 5 - TYPICAL TILE DRAINAGE SYSTEM
WEST SIDE OF THE SAN JOAQUIN VALLEY

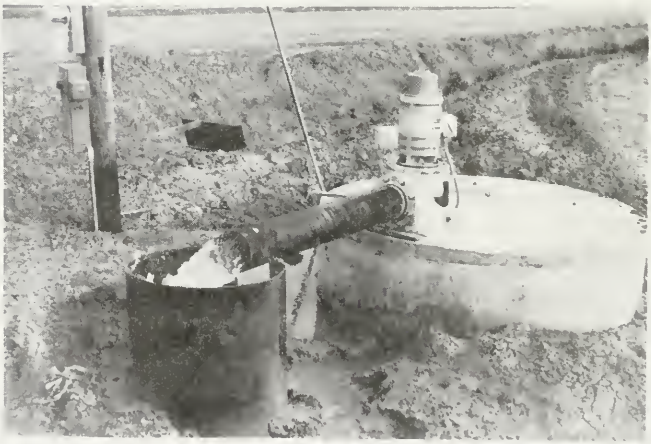

FIGURE 6. CONCRETE SUMP

Effective and Critical Placement of Tile Drain

Whenever possible, tile drainage systems are strategically placed within a field or area to alleviate high water table conditions and to prevent their recurrence. At times, subsurface water moving laterally through an aquifer can be intercepted by critical placement of the conduit, instead of by tiling an entire field (total relief). The choice of method is usually decided by farm operators who are guided by advice from drainage specialists. Several tile drainage systems in the northern area have been strategically located to intercept lateral water movement through former submerged streambeds. Many tile systems in the Gustine-Mendota area have been placed to intercept lateral movement from canals.

Physiographic Positions

The drains located along the west side of the San Joaquin Valley are found associated with soils occupying three commonly recognized physiographic positions (6). Those positions are the "alluvial fan", which extends from the base of the surrounding foothills nearly to the edge of the valley floor; the "basin rim", a relatively narrow band of alluvial, saline soils which lie between the more recent alluvial soils and the soils of the basin; and the "basin" or lowest central part of the valley floor. The alluvial fan is often divided into the "recent fan deposits", usually occurring in low-lying sites subject to fairly recent stream overflow, and "older alluvial fans" occurring at higher elevations. The manner of soil formation causes soil characteristics to differ widely from one physiographic position to another.

Recent Alluvial Fan

Soils in recent alluvial fans have been deposited by recent flooding of intermittent streams from older alluvium and parent materials at higher elevations. They are derived from out-wash materials, mostly sandstone and shale rock, and generally owe their characteristics to the character of the stratified parent material. Time has not permitted the formation of well-developed horizons within the solum. (Developed soils are those which exhibit clay movement from the surface horizon and clay accumulation in the lower horizon.)

Older Alluvial Fan

Older alluvial soils are medium-textured and have moderately or sometimes strongly developed subsoils. The parent material of these deposits is alluvium that has washed from mixed sedimentary hills of the Diablo Range. These older fans have deeply entrenched drainage ways, so new material is seldom deposited on the surface. Weathering and soil development have caused formation of rather well-defined soil layers.

Basin Rim

Parent materials of soils in this position are the same as those of the older and recent alluvium; stratigraphy and texture are often similar to the lower portions of the recent alluvial fans. The prominent differences are soil color and greater concentrations of salt in the soil profile. Structural differences may also occur when salt concentrations are predominantly the sodium ion.

Soils in this position are usually fine-textured and are generally characterized by moderate to extremely strong concentrations of alkali in the soil profile. Salts accumulate at this position because of (1) leaching and runoff from soils at higher elevations and consequent trapping in depressions on the rim and (2) because of a long continuing high water table under the basin rim soils. The second of these is perhaps the most important. Evaporation at the soil surface and transpiration by native vegetation brought large quantities of salts into the surface soil and left them there.

Basin

This group of soils comprises part of a large prominent basin that extends nearly the entire length of the San Joaquin Valley. Parent materials of soils in the basin position result primarily from eluviation from mixed granitic sediments originating in the Sierra Nevada on the east side of the Valley that were deposited by waters of the San Joaquin River, Fresno Slough, and the Kings River. Soils which lie within the basin are easily distinguished from soils in other positions. Basin soils are dark, fine-textured, and poorly drained.

Tiled Acreages within Physiographic Positions

A much greater acreage of tile has been installed in recent alluvial fans than in older fans, basin rim, or basin positions. The acreages shown in Table 1 represent all the tile systems installed up to 1969 within the Valley from Tracy to south of Bakersfield, including a few tile systems on the east side of the Valley. These acreages were determined from scaled drawings on U. S. Geological Survey quadrangle sheets, 7-1/2-minute series. Acreages are estimates based on the actual areal coverage of the tile laterals. Interceptor drains were allowed 40 acres for each one-fourth mile of conduit, when isolated from other tile systems.

TABLE 1

TILE ACREAGES WITHIN MAJOR PHYSIOGRAPHIC POSITIONS OF THE SAN JOAQUIN VALLEY FLOOR 1968

Physiographic Position	Tiled Acreage
Recent alluvial fan	17,078
Older alluvial fan	7,840
Basin rim	6,559
Basin	2,221
Total	33,698

Soils and Soil Characteristics

Soil characteristics are one of the most important factors which determine the quantity and quality of drainage in tile systems. A thorough picture of soil morphology and genesis is necessary to understand the variable soil conditions that exist along the west side.

Morphology and Genesis

The west side of the San Joaquin Valley, as referred to in this report, refers to the vast expanse of soils on the eastern slope of the Diablo Range. This area extends from Tracy to south of Bakersfield. Physiography of this area consists of gently sloping and coalescing alluvial fans that extend from the base of the mountains to a "salt rim" zone or "basin rim" surrounding the "trough" of the valley floor. Soils which occupy these different physiographic positions have developed certain characteristics which vary, depending upon the influence of one or more of the soil-forming factors. These factors are climate, organic matter, topography, and time.

The present valley floor has been built up with recent Quaternary stream deposits or with sediments of fluctuating Pliocene lakes. These deposits were composed of eroded materials transported from the drainage areas of the surrounding mountains.

Because of the arid conditions on the west side, the composition of parent material prevails as the most important single factor in the process of soil genesis. Soils that occupy recent alluvial, older alluvial, and basin rim positions have been derived from rocks of the Diablo Range. This mountain range is composed of a series of calcareous and gypsiferous sandstones, shales, and conglomerates of the Cretaceous and earliest Tertiary (Eocene) periods. A minor influent from relatively small areas of metamorphic rocks of the Franciscan formation (Jurassic) is expressed in the red coloring and basic tendencies of some of the alluvial soils. The basin soils reflect the genetic influence of mixed acid-igneous parent materials of the Sierra Nevada.

Description of Soils

Within the area of investigation, several distinctly different soil series are associated with tile drain systems. A soil series is a group of soils having horizons similar in differentiating characteristics and arrangement in the soil profile, except for texture of the surface portion, or, if genetic horizons are thin or absent, a group of soils that, within defined depth limits, is uniform in all soil characteristics diagnostic for series (7). Variations of surface texture give rise to a "soil type", the latter being a combination of the soil series name and the soil surface texture, for example, "Panoche fine sandy loam". Different soil series may develop from the same parent material depending on the degree of influence of one or more soil-forming factors. Soils occupying different physiographic positions may have formed under similar environmental conditions except for parent material, which can significantly affect the chemical and, in many cases, the physical characteristics of a soil.

Generalized descriptions condensed from U. S. Department of Agriculture soil surveys are given for individual soil series in this report. Soil characteristics which could possibly affect the quantity and quality of tile drainage are described in the subsections that follow.

Acreage subjected to tile drainage and number of tile systems for each soil series and their respective physiographic basin position are given in Table 2.

TABLE 2

ACREAGES[1/] AND NUMBER OF TILE SYSTEMS WITHIN DIFFERENT SOIL SERIES AND PHYSIOGRAPHIC POSITIONS 1968

Physiographic Position	Soil Series	Number of Systems	Estimated Acreage
Recent Alluvial Fan	Panoche	51	8,629
	Sorrento	11	3,206
	Panhill	6	650
	Foster	1	73
	Subtotal	29	12,558
Older Alluvial Fan	Lost Hills	26	4,395
	Rincon	15	2,115
	Ambrose	13	1,330
	Subtotal	54	7,840
Basin Rim	Oxalis	37	4,959
	Willows	4	800
	Levis	6	150
	Lethent	2	650
	Subtotal	49	6,559
Basin	Tulare	6	1,250
	Columbia	2	160
	Sacramento	2	153
	Hacienda	1	120
	Subtotal	11	1,683
	Grand Total	183	28,640[1/]

1/ Acreage lying outside the major tiled areas is excluded.

Soils on Recent Alluvial Fans. The Panoche and Sorrento soil series both occupy extensive recent alluvial fans along the west side. Tile drainage systems are well-represented in these two series. Only a few tile systems are located in the Panhill series and only one system in the Foster series.

All these soils are closely related in mode of formation. Soil-forming factors have not had time to act upon the soils, which are usually deep and permeable and offer little or no restriction to downward water movement in the upper portions of the soil profile. However, these soils are stratified at lower depths with sand, silt, and clay, the latter two causing perching when they are irrigated heavily. Some evidence of soil formation can be found in the Sorrento and Panhill soil series; little or no soil development occurs in the Panoche and Foster profiles.

As originally mapped in western Fresno County, the related Panoche and Panhill soils were moderately affected by salt and alkali. This is in contrast to the relatively salt-free Sorrento series. Parent materials from sedimentary sources are mainly sandstones and shales of the Coast Range.

Sorrento soils, which are located north of Gustine, are slightly darker than are the Panoche or Panhill soils of the central area. This may be due to the greater influence from nonmarine parent materials found in the area (8).

Soils of Older Alluvial Fans. The Rincon, Ambrose, and Lost Hills soil series occupy older alluvial fan positions in the study area which have developed on valley fill material derived from the same sedimentary sources as recent alluvium. The main bodies of these soils are located short distances from stream channels, but they are free from recent alluvial deposition which has resulted from changes which occurred in the main course of the depositing stream. Soils in these positions have had sufficient time to develop a well-defined subsoil in which clay and lime have accumulated. Permeability is inhibited but not restricted in the subsurface; however, the subsoils are often stratified and restriction occurs at lower depths.

The Rincon soil series is genetically related to the more recent Sorrento series in the northern area. These soils are somewhat darker and contain less alkali and other salts throughout the soil profile than does the Lost Hills series of the central area.

The Ambrose soils normally have fine-textured surfaces and heavy-textured subsoils that restrict the penetration of roots and water. The substratum, which ranges from 30 to 60 inches below the surface, consists of stratified calcareous sediments which have a lighter texture. These soils are normally free from alkali and other salts, except on the lower portions of the alluvial fan where drainage is restricted. Parent materials are a mixture of marine and nonmarine sediments.

The soil series having the greatest amount of tiled acreage is the Lost Hills series, followed by the Rincon and the Ambrose series.

Soils of the Basin Rim Position. Four major series make up the bulk of basin rim soils in the study area. These are Oxalis, Lethent, Levis, and Willows. These soils occur in the Gustine-Mendota area at the outer edges of alluvial fans along the shoreline of a former shallow inland lake. Parent materials are fine-textured, calcareous alluvium that originate from softly consolidated sandstones and shales. These soils are fine-textured, and, unless modified by irrigation, are characterized by strong concentrations of alkali and gypsum throughout the profile.

The most extensive basin rim soil belongs to the Oxalis series, which is associated with soils of the Panoche series but is typically darker, finer textured, and subject to slow surface drainage. The substratum is very often stratified with fine silty material that creates temporary perched water conditions.

The Lethent, Levis, Willows, and Oxalis soil series are very closely related and were originally mapped as a soil complex. Many tile drains are located in the abundant Oxalis series.

Soils of the Basin Position. Soils lying within the basin or trough position are generally fine-textured and dark and contain less surface alkali than do the soils of the basin rim. Parent materials are derived from mixed granitic sources from the Sierra Nevada.

The largest tiled acreage within the basin position is the Tulare series, which occupies the Tulare lakebed. Soils of this area are flat and poorly drained and at one time supported a great growth of tules. Salts contained within the highly stratified profiles tend to move to the surface unless prevented by frequent irrigation or ponding.

The soils of the Columbia series, represented by two systems located in the northern area, have been subject to frequent overflow; therefore, the profiles are relatively salt-free and somewhat stratified. Parent materials consist of mixed rock sources.

The Sacramento series, which is located north of Tracy, is also characterized by frequent overflow. These soils usually have a high organic matter content. Very little acreage has been subjected to tile drainage.

The Hacienda series is represented by a small acreage in the Tulare Lake area. These soils are more stratified and more strongly developed than are those in the Tulare series.

Climate

Climate greatly affects the quantity and quality of tile drainage along the west side. Heavy rainfall causes leaching of surface soil and, when excessive, may cause increases in tile flow and changes in quality. Too little rain and high temperatures result in increased irrigation, which directly influence tile discharge and its quality.

Temperature

The climate along the west side of the San Joaquin Valley is typically arid, with maximum daytime temperatures frequently exceeding 100°F in July and August. Average annual temperatures vary only slightly from one climate station to another; differences between years are also small, as shown in Table 3.

TABLE 3

AVERAGE ANNUAL TEMPERATURE
AT SELECTED WEATHER STATIONS 1/
ALONG THE WEST SIDE

Location	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Tracy Carbona	62.0	61.6	61.2	59.7	59.5	60.7	60.1	61.7	61.3	61.2	61.4
Westley	NR	64.3	64.9	61.7	60.5	61.0	63.0	62.4	59.2	61.1	62.8
Newman	61.4	61.2	61.0	60.1	59.7	60.2	60.3	61.5	60.7	60.9	60.5
Los Banos	63.5	62.4	62.2	61.3	60.7	60.7	61.6	62.7	62.1	62.8	61.4
Corcoran	NR	63.3	62.4	61.8	61.2	61.8	61.8	63.3	62.6	62.8	62.1

1/ U. S. Weather Bureau, Department of Water Resources, and cooperative stations.

NR = No record.

These data were obtained from a weather station located in the heart of well-established agricultural areas. Average maximum temperatures are higher and minimum temperatures are lower in these areas than on the large alluvial fans adjacent to the foothills where irrigation is limited. According to studies (9) conducted by the Department of Water Resources, topography appears to influence air temperature extremes more strongly than does agricultural environment.

Evapotranspiration and evaporation reach their upper limits during July and August. Irrigation in the Valley increases rather consistently with rising temperature. Figure 7 shows monthly average temperatures at Los Banos for 1968.

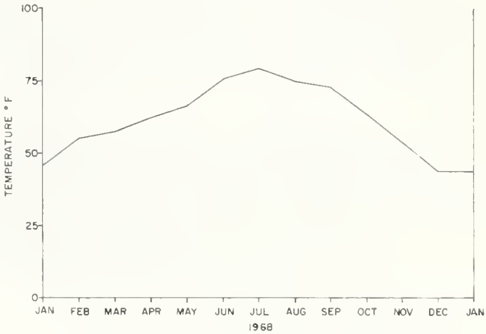

FIGURE 7 - MONTHLY AVERAGE TEMPERATURE AT LOS BANOS

Precipitation

Less than a quarter inch of precipitation falls along the west side between the months of June and September; consequently, relative humidity remains low during these months. High temperatures and prevailing northwest winds combine to produce very high rates of evaporation and evapotranspiration, which means most crops need intensive irrigation.

Precipitation is somewhat irregular from Tracy-Carbona in the north to Corcoran in the south. The amount of precipitation decreases to the north and to the south from Gustine. Influence from coastal storms can be seen in the data presented in Table 4. According to the data, for the period of study, precipitation as far north as Tracy has not greatly exceeded that recorded at Corcoran.

Although the data show higher precipitation toward the trough of the Valley, rainfall seldom exceeds 6 inches over much of the area adjacent to the foothills of the Diablo Range.

Agriculture and Agricultural Practices

The types of agriculture practiced in an area may influence the quantity and quality of tile drainage. For instance, tiled areas that are devoted mainly to dairy farming receive

TABLE 4

ANNUAL PRECIPITATION
AT SELECTED WEATHER STATIONS 1/
ALONG THE WEST SIDE

Location	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Tracy Carbona	7.71	7.30	7.49	8.51	9.47	7.97	10.18	6.39	10.79	14.31	10.22
Westley	9.78	8.12	7.92	10.87	12.57	8.81	10.68	6.70	10.28	9.55	13.31
Newman	11.13	8.81	8.78	10.39	14.95	9.39	11.54	7.75	11.44	8.80	16.77
Gustine	11.23	10.52	NR	NR	15.38	9.00	12.43	7.22	11.91	9.60	17.22
Los Banos	6.56	8.16	7.12	9.34	10.93	9.16	10.65	6.87	9.21	7.45	14.42
Dos Palos	5.48	7.93	6.58	8.13	10.27	6.95	8.97	4.70	7.60	9.26	11.94
Mendota Dam	5.28	7.13	7.25	7.48	8.70	6.17	7.29	5.41	9.06	7.80	11.72
Corcoran	3.19	6.74	4.66	5.89	8.92	5.51	6.30	5.23	6.96	6.11	12.66

1/ U. S. Weather Bureau, Department of Water Resources, and cooperative stations.

NR = No record.

little commercial fertilizer but are heavily irrigated. Highly diversified areas receive varying applications of irrigation water but are apt to have a regular fertilization program.

Agricultural trends may change fertilization and irrigation programs, which may in turn affect the quantity and quality of tile drainage.

Crops

Historically, farming practices on the west side have followed those in the rest of the San Joaquin Valley, evolving slowly in three distinct but overlapping stages. These stages include a period of cattle and sheep raising, a period of grain farming, and the present period of diversified agriculture dependent upon irrigation. Dry farming, once popular for growing wheat, began to decline in favor of irrigated grain and alfalfa sometime after 1900 when irrigation districts began to form. Also about this time reclamation districts in the Tulare lakebed were organized to protect grain farmers from flooding waters of the Kings and Tule Rivers.

Through the years cattle raising and dairy farming have continued to be an important part of the agriculture in the area between Westley and Gustine. The area around Byron and Westley, once very popular for grain farming, has tended toward truck crops and orchards in the last decade. Cattle raising was also popular in the Gustine-Mendota area until about 1920, when irrigation became more extensive. After 1945, cotton, flax, and rice became more important and cattle ranches disappeared. Cotton remains an important crop, but truck crops have increased steadily even at the expense of some cotton acreage. Cotton has been grown extensively in the area from Tulare Lake to Gustine, although very little cotton can be found north of the City of Newman where lima beans are grown widely.

Double-cropping is a common practice in the Gustine-Mendota area. Rice and barley are the most notable combinations; however, several other combinations are found. The practice of allowing a parcel of land to remain fallow over a period of months has declined in this area due to the economic demands that now are placed on the land.

Current Irrigation

Irrigated agriculture in the San Joaquin Valley has become more prevalent as features of the Central Valley Project and the State Water Project have developed.

Sources. In the study area, all fields investigated were furnished with canal water imported chiefly from the Delta. The exception was the Tulare Lake area, where water is routinely pumped and recirculated through an elaborate network of canal and levee systems. Water applied to a given field depends entirely upon the individual management of the farmer, the crop needs, and the quality of water available. The amount of water needed to grow a particular crop (consumptive use) is nearly the same from one end of the Valley to the other. However, crop irrigation requirements (10) differ from place to place, depending upon the climate in an area and the type, maturity and condition of crops grown. Adverse soil conditions such as coarse texture and alkalinity can greatly affect the development of crops in some cases and thereby affect their water requirement.

Types of Irrigation. In the study area, furrow irrigation is the method used most often on truck and field crops. Grain and safflower crops are generally irrigated only once during the year, if at all.

Preirrigation, a method for providing soil moisture in the early spring for seed germination, is a common practice throughout the entire area.

Sprinkler irrigation is practiced on some of the highly permeable soils on the west side, especially in the Gustine-Mendota area. It is rapidly growing in popularity. The check irrigation method is used for pasture, alfalfa, and orchard crops. Rice crops, limited mostly to the central area, are flooded during June through early August.

SECTION IV

METHODS AND MATERIALS

This section describes the methods and materials used in monitoring tile drainage systems for the period of study.

Monitoring Tile Drainage Systems

A brief history of tile drain monitoring is presented to show the necessity for an intensified monitoring program. A greater emphasis was placed on the selection of tile drains, field monitoring techniques, and collection of agricultural and soils data during the more recent studies than in the past.

Historical Monitoring

Initial investigations of tile drainage began in 1959 as part of the Agricultural Waste Water Quality Studies, a cooperative program between the Department of Water Resources and the Water Resources Center of the University of California. During these studies, the emphasis was placed on the quantity and quality of surface and subsurface agricultural wastewater. The frequency of sampling for tile systems at that time was somewhat limited; 104 nutrient samples were collected from 29 systems over a four-year period. Most of these systems (25 out of 29) were located in the central area; the other four were located in the northern area.

Samples were not collected from tile systems in 1964 and 1965. However, in 1966, seven tile systems were selected for more intensified sampling in the central area. Later the same year, reconnaissance investigations showed that drainage from other tile systems in the same area contained much higher concentrations of nitrogen than those currently being sampled. At the same time, drainage from tile systems in the Byron-Westley and Tulare Lake areas was found to be lower in nitrogen concentrations. The foregoing investigations led to the eventual expansion of the monitoring program to include as many as 40 individual systems in 1967 and 42 systems in 1968. Intensive investigations were not initiated in the Byron-Westley area until May 1967; all other major tiled areas were sampled for the full calendar year. In 1968, all 42 tile systems within the major tiled areas were sampled intensively for the entire year. In addition, 18 satellite systems and a few isolated tile drains were also monitored, but on a less frequent basis. The monitoring program was greatly reduced in 1969; samples were collected on a monthly basis from only 20 tile systems.

Selection of Tile Drainage Systems for Monitoring

Large, well-designed tile drainage systems having good agricultural management were quite easy to find during the initial investigations when only a few systems were required for study. However, selection became increasingly difficult when a number of representative tile drainage systems were sought with regard to specific soils, physiographic positions, and certain agricultural practices. These and other factors were considered paramount in selecting an individual tile drainage system to be monitored. These are listed in their order of desirability.

1. Location. Several systems were chosen to represent the four major tiled areas. Isolated systems and satellite systems were chosen for supplemental data.

2. Size. Larger systems were preferred to smaller ones in hopes of reflecting drainage from a large area of soils.

3. Design. "Total relief" systems were chosen for greater representation of soil conditions in preference to "interceptor" type drains.

4. Agricultural Practices. Tile systems draining fields having an active irrigation and fertilization program were selected.

5. Physiographic Positions and Soils. Tile drainage systems occupying different physiographic positions and representing various soils were also selected.

6. Sumps and Outlets. Tile systems with sumps were selected for convenience of sampling and flow measurement.

7. Age. A range of ages from 1955 to 1967 was selected. Very few tile drains were installed in the Valley prior to 1950.

Selecting tile drains was at times difficult, because very few had all the desirable features. Generally, as many tile drains with the foregoing factors were chosen as possible within the major areas of interest.

Acreages Monitored. The number of acres tiled was not determined for the systems sampled from 1959 to 1963. During 1966 approximately 1,545 acres were sampled in the Gustine-Mendota area. Table 5 presents a summary of acreages devoted to agricultural subsurface drainage systems and acres sampled for nutrients within the major tiled areas of the San Joaquin Valley in 1967 and 1968.

TABLE 5

ACREAGE* TILED AND ACREAGE SAMPLED
FOR NUTRIENTS IN MAJOR TILED AREAS

Major Tiled Area	Acreage Sampled 1967	Tiled Acreage 1967	Acreage Sampled 1968	Tiled Acreage 1968
Byron to Westley	1,687	4,554	1,934	4,775
Westley to Gustine	1,559	1,959	1,559	2,139
Gustine to Mendota	3,779	16,310	4,879	20,343
Tulare Lake Drainage District	953	1,443	1,273	1,443
TOTALS (MAJOR AREAS INVESTIGATED)	7,979	24,266	9,645	28,700
ALL OTHER DRAINAGE AREAS (ISOLATED TILE SYSTEMS)	848	4,998	848	4,998
TOTALS	8,827	29,264	10,493	33,698

*Acreages were estimated from scaled drawings on U.S.G.S. quad sheets (1/4 mile of interceptor line was assumed to drain 40 acres).

A few tile systems lying outside the major tiled areas were also sampled. Acreages representing these systems are shown separately in Table 5.

Tile acreage sampled increased from 1967 to 1968, due to the addition of two new tile systems to the monitoring program; also, several of the systems being sampled were expanded. About 53 percent less acreage was monitored in 1969 than in 1968, due to a reduction in the program.

Table 6 summarizes the number of tile systems and acres sampled in 1968 within different physiographic positions and soil series. These tile systems are located within the major tiled areas of the Valley and are the ones that were intensively sampled. Acreages of isolated or satellite tile drainage systems within specific positions or soils were not determined.

TABLE 6

TILE DRAINAGE SYSTEMS AND ACRES SAMPLED
BY SOIL SERIES AND PHYSIOGRAPHIC POSITIONS
WITHIN THE MAJOR TILED AREAS
1968

Physiographic Position	Soil Series	No. of Systems	Acres
Recent	Panoche	8	2,071
Alluvial	Sorrento	6	2,356
Fan	Panhill	4	595
	Foster	1	73
Older	Rincon	4	895
Alluvial	Ambrose	3	169
Fan	Lost Hills	3	858
Basin	Oxalis	4	825
Rim	Lethent	2	390
	Willows	1	140
Basin	Tulare	4	1,080
	Sacramento	1	73
	Hacienda	1	120
Total		42	9,645

Tile Monitoring Techniques

The monitoring program consisted of measuring tile discharge and collecting samples of tile drainage for analyses of nutrients and total dissolved solids. Mineral samples were collected during the winter and summer of each year; dissolved oxygen samples were only collected once during the investigation.

Flow Measurement. Tile drainage discharge was measured whenever samples were taken. Several methods were used to determine the flow, depending upon the design of the individual tile outlet or discharge structure. All methods used were volumetric procedures set forth in numerous standard irrigation and drainage texts or necessary modifications of the standard techniques.

The two methods used most in this study are the "bucket and stopwatch method", used mostly for small flows, and the "float method", a technique devised to measure very high flows inside sumps. The latter method requires a water stage recorder float, an engineer's tape, and a stopwatch (Figure 8).

FIGURE 8. "FLOAT METHOD" FLOW MEASUREMENT

Other methods employed under certain conditions included a velocity meter, the "V" notch weir, pump rating and meter readings, a Parshall flume, and other combinations.

Nutrient Sampling. Samples were collected in plastic pint bottles directly from tile outlets, sump pump discharge pipelines (Figure 9), or from inside the sump and stored in ice chests to inhibit possible denitrification during transport to the laboratory.

Nutrient samples were collected on a weekly basis from all the tile drainage systems included in the intensive investigations (1966-68). Several "satellite" stations which were located in the Byron-Westley and Gustine-Mendota areas were sampled monthly during 1968. Isolated tile systems were sampled weekly for eight months in the same year. Prior to 1966, occasional samples were collected at random from several stations. A definite sampling frequency was not established until 1966.

FIGURE 9. SAMPLING METHODS -- NUTRIENTS

Collection of Mineral Samples. Mineral samples were collected routinely during the initial investigations and less frequently during the last few years of the study. These samples were collected as back-up data for the nutrient investigations and as a basis for determining other forms of nitrogen and related constituents in the tile drainage.

Collection of Dissolved Oxygen Samples. Effluent from 15 subsurface agricultural drainage systems was examined for concentrations of dissolved oxygen (DO) to compare DO concentrations in drainage between tile systems in different major tiled areas. Five systems were sampled in each of the following major tiled areas: northern (Byron-Gustine), central (Gustine-Mendota) and southern (Corcoran-Wasco).

Samples were collected from tile outlets, tile discharge sumps, gravity drain pools and pump discharge pipelines. A long, rigid plastic tube was used to obtain samples from inside tile outlets.

Laboratory Techniques

As many as 300 samples per month were collected during 1967 and 1968. Nitrate and phosphate determinations had to be made as soon as possible after sampling to prevent possible biological changes of nutrients in the samples. At times, day-to-day changes of nitrogen concentrations in tile drainage also had to be determined. The methods used to determine nitrates, phosphates, and electrical conductivity, and to prepare soil extracts are discussed in this subsection.

Nitrogen Determinations. Nitrogen determinations of tile drainage were made solely by the Department of Water Resources' laboratory at Bryte, California, prior to 1966. The Brucine method (11) is the accepted method used by the DWR laboratory to determine nitrates.

During this investigation most of the nitrogen determinations were made in the San Joaquin District water quality laboratory by the cadmium reduction method of nutrient analysis, which was determined to be sufficiently accurate for monitoring nutrients in tile drainage from the San Joaquin Valley. This method relies on the conversion of nitrate to nitrite. It is basically a colorimetric determination using a photoelectric cell and a fixed wave length filter. This method was selected for two reasons: (1) because immediate analyses of a large number of samples could be made rapidly with an accurate account of the nitrate-nitrogen concentrations, and (2) nitrates constituted more than 90 percent of the nitrogen in the tile drainage. (Organic and ammoniacal nitrogen was found to be less than 1 milligram per liter in tile drainage according to Kjeldahl analyses made by the DWR laboratory.)

The cadmium method was first used for determining the general range of nutrients in the field. Accuracy and precision were later improved, due to the availability of better reagents and the development of a continuous standardization and checking process. A "standard curve" was established to maintain accuracy of the nitrate determinations throughout the study. In order to do this, an array of nitrate standards were obtained from the DWR laboratory that ranged from 5 to 400 mg/l. Repeated tests were made on these samples in order to determine the transmittance for different standard concentrations. From these data a "standard curve" was established to which samples containing unknown concentrations could be compared. An average standard deviation of less than 4.0 percent was achieved time after time for a series of laboratory-prepared nitrate standards that ranged from 15 to 280 mg/l.

As part of the checking process, approximately 5 percent of the field samples were split between the two methods of analysis. A statistical comparison showed a correlation coefficient of 0.992 for 77 split samples; other spot comparisons also showed a close correlation between the two methods.

Phosphorous Determinations. A modified stannous chloride method was used to determine phosphates (orthophosphate), using the same colorimeter as that used in the nitrate tests. Standardization curves were established and checked in the same manner as in the nitrate tests in order to maintain optimum control and the same high degree of accuracy.

In standard phosphate solutions ranging from 0.1 to 6.0 mg/l, the average standard deviation was 3.67 percent of the mean.

A detailed account of the methods used in determining nutrients, the techniques used for maintaining accuracy and precision, and statistical comparisons made during the course of the investigation is in the Department's files.

Electrical Conductivity. A conductivity bridge was used to determine the electrical conductivity (EC) of the tile drainage water and soil extracts. These tests were run in the laboratory along with the nitrogen and phosphate determinations. A factor of 0.7 was used in converting EC values (micromhos x 10^{-6}) to total dissolved solids (TDS, mg/l). This is an average factor determined from mineral laboratory reports.

Soil Extracts. Nitrate analyses (cadmium reduction method) of soil samples were made on extracts that were suction-filtered from a saturated soil paste. Soil extracts were refrigerated prior to analysis to minimize possible denitrification.

Collection of Agricultural Data

Agricultural practices data which include the type of crops grown and the quantities of nitrogen fertilizer applied were recorded for every tile system investigated during 1966 and 1967. Irrigation application rates and quantities of runoff were determined for several tile systems from 1959 to 1963.

Crops

Cropping data were collected from individual farm operators and irrigation district offices of the actual crops grown for any tile system between the years 1959 through 1967.

Irrigation

Actual amounts of applied irrigation water were determined for a number of tile-drained fields from 1959 to 1963.

Headgate irrigation requirements (quantities of water required in the production of various crops, exclusive of precipitation) were used in lieu of actual applied water data for determining irrigation requirements in major tiled areas during 1967 and 1968.

Samples of applied water were collected during irrigation to determine the relative amounts of nitrogen being applied in the irrigation water. These samples were analyzed for nitrate, phosphates, and electrical conductivity. Laboratory results showed very low concentrations of nitrogen in forms other than nitrates. Nitrate-nitrogen (NO_3-N) in the irrigation waters was found in concentrations of 4 mg/l, which amounts to about 11 pounds of nitrogen per acre-foot of water applied.

Phosphate-phosphorous (PO_4-P) concentrations in irrigation water were nearly always less than 0.5 mg/l. Electrical conductivity usually ranged from 250 to 350 micromhos.

Irrigation Runoff

Although irrigation runoff was only measured during the initial investigations, samples were collected to determine the nitrogen concentration. Nitrogen (NO_3-N) averaged about 6 mg/l for all of the samples collected.

Fertilization

Fertilization has been considered by many to be one of the most important factors contributing to nutrients in tile drainage systems. To investigate the quantities of nitrogen available for leaching and possible accumulation in the subsurface waters, historic and current fertilization rates were obtained. These are discussed in this subsection. Certain aspects of nitrogen gains and losses are also discussed. However, a nitrogen-balance study was not the intent of this investigation.

Historical Use of Fertilizers. Commercial nitrogen fertilizer has been used in the areas around Gustine, Mendota and Tulare Lake area for the last 30 years. In the area from Byron to Gustine, fertilization has been limited by dairy farming and raising of lima beans, a legume which does not require fertilization. However, orchards between Byron and Gustine have been fertilized regularly with ammonium-sulfate fertilizer at the rate of 4 to 8 pounds per tree (about 80 to 100 trees per acre). Although fertilizer use is still somewhat limited by the type of crop grown in the northern areas, farmers near Tracy apply nitrogen fertilizer to most truck and field crops at 60 to 100 units per acre, which is very close to that applied in the central and southern areas.

Application rates of nitrogen fertilizer have generally increased in the past ten years. The rates for cotton, rice, barley and safflower have nearly doubled on many farms in the central area since 1960. This has been brought about by recommendations of farm advisors and consultants for fertilizer companies. Furthermore, an increased usage has also resulted in some areas from plantings of lettuce, bell peppers and other such high-fertilizer-use crops.

Types and Methods of Use. Both commercial and natural fertilizers were used in the tile-drained areas. The methods of application depend a great deal on the types being used which are discussed in the following subsection.

Commercial Fertilizers. Various forms of nitrogen fertilizer are popular in the study area; ammonium-sulfate, urea, and aqua-ammonia are the most popular. Row crops are generally banded with fertilizer, whereas some field crops, such as barley and rice, have areal applications. Urea fertilizer is used almost exclusively to reduce denitrification losses in rice crops.

Phosphate fertilizers have been used to a limited extent on the west side; however, regular applications are made to large acreages of soil in the Tulare Lake area.

Animal and Green Manures. The amounts of nitrogen added from animal manure and green manure (cover crops) were not determined because these materials contain minimal amounts of nitrogen. Average farm manure generally contains less than 0.5 percent nitrogen by weight, and the amounts provided by green manure crops are extremely variable (12).

No attempt was made to determine the amounts of nitrogen contributed by legume crops such as alfalfa or beans. The amount of atmospheric nitrogen "fixed" by legumes is quite variable; also, the amount of nitrogen added to the soil after several years growth of a leguminous crop is questionable (13).

Volatilization. Volatilization losses after fertilization can be high under certain conditions (14). However, for this investigation, volatilization losses were considered more than offset by the quantities of nitrogen added in irrigation water.

Data Sources. Records of commercial fertilizer applications were collected along with the cropping data. Estimates of missing or inadequate data for a given crop were based on fertilizer recommendations of farm advisors or local fertilizer companies for a particular year.

Investigations of Native Nitrogen

In addition to routine monitoring of tile drainage systems, indigenous nitrogen in soil profiles was investigated in the field. A literature review concerning residual nitrogen in parent materials was also performed.

Soil Profile Nitrogen Sampling

Forty-five soil profiles representing different physiographic positions and soil series were sampled for indigenous nitrogen along the west side. Virgin sites were sought to obtain the quantity of nitrogen in the soil before irrigation. Several dry-farmed and irrigated sites were also sampled. All profiles were logged for soils occupying recent alluvial fan, older alluvial fan, basin rim, and basin physiographic positions. Sites were hand-augered to a depth of 10 feet or more and samples were collected at 1-1/2-foot increments for nitrogen analyses.

Parent Material Nitrogen Sampling

Data on residual nitrogen concentrations of parent materials* were obtained from investigations (15) conducted in 1959 along with deep boring investigations, to determine sources of high nitrates observed in shallow ground water on the east and west sides of the Valley. Alluvial parent sources (cretaceous marine sediments of the Diablo Range) in selected drainage ways (Arroyo Hondo and Arroyo Ciervo) were sampled, including an array of different materials, such as zones within the stratum, mudflows, cross sections of arroyos, mud puddles, and streams.

*Provided by the Agricultural Research Service.

SECTION V

RESULTS AND DISCUSSION

This section discusses the average nutrient concentrations and discharges from tile drainage systems monitored. Emphasis is placed on long-term and short-term nutrient variability, seasonal and areal variability, and variability due to agricultural practices, physiography, and soils. Indigenous nitrogen in virgin soils, irrigated soils, and parent materials is also discussed.

Average Nutrient Concentrations

The grand average concentration of nitrogen (nitrate-nitrogen) in composited drainage discharged from all systems intensively investigated throughout the entire period of study was 19.3 mg/l. This concentration is very close to the 21 mg/l value predicted in Bulletin No. 127 (1) by the Department of Water Resources.

Eighteen "satellite" systems, selected at random within the major tiled areas, were monitored to obtain "back-up" data and to determine the feasibility of monthly sampling. The composited drainage (individual nitrogen concentrations weighted by tile flow) averaged 23.6 mg/l for an eight-month period.

The composited drainage for all the tile systems monitored regularly in the major tiled areas, the isolated stations outside the areas, and the "satellite" stations averaged 20.0 mg/l nitrogen.

The average concentration of phosphorus (orthophosphate) in drainage composited from the intensively monitored major tiled areas averaged 0.09 mg/l, slightly less than the 0.15 mg/l predicted in Bulletin No. 127.

Average Discharge

Tile drainage discharge averaged 1.4 acre-feet per acre for the same period of study; total dissolved solids (TDS) averaged 3,625 mg/l. The 1959-63 values were excluded from the grand average values given because the nutrient or TDS constituents could not be weighted by flow. They are presented in Table 7 for comparison.

TABLE 7

AVERAGE DISCHARGE, NUTRIENT CONCENTRATIONS, AND TOTAL DISSOLVED SOLIDS FROM SAN JOAQUIN VALLEY TILE DRAINAGE SYSTEMS

Parameters	Annual Averages (Weighted)						Grand Average[2/]
	DWR (Bull. 127)	UCLA	DWR Nutrient Investig.				
	1959-63[1/]	1962	1966	1967	1968	1969	
Discharge (ac-ft/ac)	NR	0.72	1.5	1.3	1.4	1.4	1.4
Nitrogen (NO_3-N, mg/l)	21.0	25.1	18.6	18.6	19.9	19.4	19.3
Phosphorus (PO_4-P, mg/l)	0.15	0.08	NR	0.12	0.10	0.05	0.09
Total Dissolved Solids (mg/l)	6,500	NR	4,550	3,100	3,200	3,550	3,625
Number of Systems Sampled	29	4	7	40	42	20	--

1/ Values are arithmetical averages.
2/ Weighted average based on flow.
NR = No record.

Variability of Nutrient Concentrations and Tile Discharge with Time

Long-term and short-term variabilities of average nutrient and TDS concentrations and discharges are discussed in this subsection.

Long-term Nitrogen Variability

Long-term variability deals with the changes in average discharge observed from the study area over several years and the related changes of nutrient concentrations that take place in the composited drainage. Variability of nitrogen in individual tile systems is also compared.

Composited Drainage. Although the figures in Table 7 represent the weighted average values for the different periods of study, some variability exists between years. The differences in discharges and tile drain constituents between years are small, considering the number of tile systems sampled and the geographical areas represented for any given period. For instance, in 1962 the highest average nitrogen concentration (25.1 mg/l) occurred in the composited drainage from four tile systems within the Gustine-Mendota area. In 29 systems sampled in 1959-63, most of which were situated in the same area, the concentration was only 4.1 mg/l less.

Closer correlations between annual nitrogen concentrations occurred during the more intensive investigations conducted from 1966 to 1969. Average nitrogen concentrations for 1966 and 1967 were identical. However, the data for 1966 were based on just seven tile systems in the central area, whereas the data for 1967 were based on forty systems located throughout the San Joaquin Valley.

The small difference between 1967 and 1968 may have occurred because only seven months' data were obtained in the northern area during 1967 and the acreage sampled was slightly less. The 1969 value of 19.4 mg/l, which also compares favorably, is based on a monthly sampling frequency of fewer than half the systems sampled in 1968.

Average discharge (based on the total acre-feet discharged per estimated areal tiled acres) was nearly the same for all years, except during the studies conducted by the University of California, Los Angeles, when only four tile systems were investigated.

Phosphorous concentrations in composited drainage were nearly the same for 1967 and 1968 but were much lower in 1969, when the Tulare Lake area could not be sampled because it was flooded. Although phosphorous concentrations appear to change little from year to year, the percent of change is higher for phosphorus than it is for nitrogen.

The high TDS value for 1959-63 is based on "salt routing" investigations conducted by the Department of Water Resources (1). The average value (flow-weighted) of 4,550 mg/l was determined from seven systems in the Gustine-Mendota area. This is a significantly higher value than the values obtained for 1967 and 1968.

Individual Systems. Although average nitrogen concentrations changed little from year to year in drainage composited from the study area, leaching and fertilization were thought to affect the nitrogen concentrations in individual systems on a long-term basis. Therefore, in an attempt to evaluate the possible long-term variability of nitrogen, all historic sampling records available for individual tile systems were analyzed. Twelve tile systems were selected for which records showed occasional sampling prior to 1966. These data are presented in Table 8. Data for individual stations from 1966 to 1969 are based on weekly samples collected over a full year and monthly samples collected in 1969.

Flow values in gallons per minute (GPM) and concentrations of total dissolved solids (TDS) are shown for comparative purposes. The values given for flows represent the average

TABLE 8

NUTRIENTS, TOTAL DISSOLVED SOLIDS AND
FLOWS FROM INDIVIDUAL TILE DRAINS BY YEAR

Tile System	Drain Constituents and Flows	Year							
		1959 1/	1961 2/	1962 2/	1963 1/	1966 3/	1967 3/	1968 3/	1969 4/
BAY 0711	NO_3-N (mg/l)	3.6	2.0				7.9	7.4	
	TDS (mg/l)	2,590	2,756				5,000	4,100	
	Flow (GPM)	41	12				3	5	
CLG 7551	NO_3-N (mg/l)		3.4				6.5	8.2	11.2
	TDS (mg/l)		2,510				2,786	2,975	2,583
	Flow (GPM)		150				179	187	341
CLG 7651	NO_3-N (mg/l)	4.3	2.4				9.6	11.4	11.3
	TDS (mg/l)	2,910	2,357				2,700	2,940	2,670
	Flow (GPM)	183	56				161	196	92
DPS 4616	NO_3-N (mg/l)		2.1		1.3		5.2	3.7	9.0
	TDS (mg/l)		12,800		12,600		6,867	4,000	9,515
	Flow (GPM)		130		7.0		69	130	130
BFS 8003	NO_3-N (mg/l)			6.6			6.4	6.7	5.1
	TDS (mg/l)			14,300			10,300	8,400	7,555
	Flow (GPM)			15			36	97	77
BFS 7402	NO_3-N (mg/l)		8.5			13.4	11.1	10.0	15.7
	TDS (mg/l)		3,776			4,403	3,700	3,640	4,810
	Flow (GPM)		171			409	211	482	521 5/
FBH 8061	NO_3-N (mg/l)	7.9	3.6				5.6	4.8	2.0 5/
	TDS (mg/l)	8,120	8,360				3,870	3,720	2,910 5/
	Flow (GPM)	162	68				81	190	
BFS 6001	NO_3-N (mg/l)		10.0			11.2	18.2	13.3	
	TDS (mg/l)		3,100				3,976	2,850	
	Flow (GPM)		87			457	120	260	
FBH 5056	NO_3-N(mg/l)	61.3	36.8	37.2	51	50.0	37.1	49.4	53.7
	TDS (mg/l)	9,720	6,700	7,586	9,480	6,200	5,000	6,550	6,280
	Flow (GPM)	42	84	79	10.0	31	129	63	53
FBH 2016	NO_3-N (mg/l)		10.4				6.6	5.1	9.3
	TDS (mg/l)		6,885				4,300	2,100	4,750
	Flow (GPM)		16				39	124	79
ERR 6705	NO_3-N (mg/l)		12.4				15.9	13.7	
	TDS (mg/l)		3,487				3,600	3,675	
	Flow (GPM)		63				111	50	
CCN 3550	NO_3-N (mg/l)		5.4				8.4	6.7	
	TDS (mg/l)		2,627				2,300	2,260	
	Flow (GPM)		136				182	118	

1/ Values represent one to three samples collected at each station.

2/ Values represent one to fifteen samples collected at each station.

3/ Values represent weekly samples for a full year.

4/ Values represent monthly samples for a full year.

5/ Values represent only one sample.

flows of only a few measurements at different times of the year prior to 1966. Time-weighted average flows were computed from data obtained during the more intensified studies. Average TDS concentrations were determined from available mineral data prior to 1963 and flow-weighted from electrical conductivity values thereafter.

The data show evident variability of nitrogen concentrations in drainage between years for nearly all the systems. The changes in nitrogen concentrations can possibly be explained in that many of these stations were sampled at different times of the year and are represented by changes in agricultural practices (i.e., crops and irrigation).

By making comparisons of two distant periods of most complete data (1961 and 1968), the following observations were made:

1. Nitrogen concentrations increased in ten out of eleven systems over a seven-year period.

2. TDS concentrations decreased in seven out of eleven systems for the same period.

3. Nearly as many tile systems decreased in flow as increased.

Increases of nitrogen were also noticed during the periods of more intensive sampling (1967 through 1969 inclusive). Six out of eight systems showed increases in nitrogen concentrations and, again, these increases were not particularly related to changes in flow or concentrations of TDS. Although limited data were available for the earlier years and nitrogen concentrations varied greatly between years for some of the drains studied, two facts remain clear: (1) there is no apparent trend that might indicate leaching or an accumulation of nitrogen in the soil over long periods, and (2) tile systems having rather high initial nitrogen concentrations remain rather high.

Short-term Nitrogen Variability

Nitrogen and phosphorous concentrations in drainage from all systems investigated varied according to the season. Frequent irrigation tended to lower the nutrient concentrations in most of systems monitored, and highly erratic variations of nutrient concentrations were observed during irrigation of many systems. Nitrogen concentrations as observed in the field and from graphical analyses of individual systems would increase, decrease, or remain about the same during irrigation at a particular site. No matter what the response, when irrigation ended, nutrient concentrations nearly always tended to return to the levels observed prior to the beginning of the irrigation season.

Nutrient, TDS, and flow variabilities were investigated hourly and daily for several tile systems. As part of the analysis, monthly variability of flows and nutrients was determined for every system studied.

Hourly. Nitrogen concentrations were first observed to vary in drainage from individual systems where frequent samples were collected for treatment studies (Interagency Agricultural Wastewater Treatment Center at Firebaugh, California). Investigations were later conducted at four sites to determine the actual nitrogen variation that occurs in drainage from one hour to the next and to aid in determining a proper sampling frequency.

Sampling was scheduled to coincide with periods of irrigation to make the most of possible nitrogen variations and to determine the possible effects of dilution. Samples were collected and analyzed by routine methods set up for the monitoring program. Results of the hourly investigations appear in Table 9; variable phosphorous concentrations, electrical conductivity values, and flows are compared.

TABLE 9

HOURLY VARIATION OF FLOWS, NUTRIENTS AND ELECTRICAL CONDUCTIVITY IN DRAINAGE FROM FOUR TILE DRAINAGE SYSTEMS

System	Flows (gpm)				Nutrients								Electrical Conductivity (E.C. x 10^{-6})			
					NO_3-N, mg/l				PO_4-P, mg/l							
	Max.	Min.	Mean	Std. Dev.	Max.	Min.	Mean	Std. Dev.	Max.	Min.	Mean	Std. Dev.	Max.	Min.	Mean	Std. Dev.
UID 2133	382	382	382	0	12	4	8.0	1.83	0.75	0.13	0.56	0.16	3,000	2,900	2,950	29
BFS 7402	594	561	571	10.2	49	24	40.2	6.24	0.26	0.06	0.16	.051	4,600	4,200	4,400	69
FBH 3236	194	134	156	19.3	185	92	166.0	19.8	0.45	0.15	0.24	.073	12,000	9,400	11.230	716
CCN 3550	273	193	224	22.2	49	18	30.0	6.47	1.60	0.75	1.16	0.19	3,000	2,200	2,642	239

A mean nitrogen value was determined for weekly samples collected one month before and one month after the 24-hour studies. The mean weekly values compared well with mean hourly values of the same systems in three cases (Table 10).

Daily. At the beginning of the intensive monitoring investigations, samples were collected at close intervals (three to four days), and daily in some instances, until an appropriate

TABLE 10

HOURLY VS. WEEKLY NITROGEN CONCENTRATIONS

System	Nitrate-Nitrogen (mg/l)			
	Weekly 1/		Hourly 2/	
	Range	Mean	Range	Mean
UID 2133	8- 39	19	4- 12	8
BFS 7402	24- 59	38	24- 49	40
FBH 3236	82-230	144	92-185	166
CCN 3550	18- 46	30	18- 45	30

1/ Two-month period.
2/ Twenty-four hour period.

sampling frequency could be established. In samples collected daily, nitrogen concentrations varied slightly from day to day but tended to remain generally constant, unless the field in question was being irrigated. Intensive irrigations effectively reduced the nitrogen for short periods in many cases. The longest period of consecutive sampling covered five days at one station. Nitrogen concentrations in the drainage ranged from 30.5 to 45.1 mg/l. The mean value was 35.5 mg/l, with a standard deviation of 6.3 mg/l (18 percent).

Samples collected at three-to-four-day intervals showed a greater variation than those collected daily. In a random example which was sampled 11 times during the month, the standard deviation was 9.7 mg/l, or 30 percent of the mean concentration of 30.6 mg/l. Similar variations were observed in the data collected from the other systems sampled at three- and four-day intervals during a period of irrigation.

The foregoing data led to the decision that weekly sampling was adequate for the investigation. This determination was based on the following findings: (1) mean hourly nitrogen concentrations show a correlation to mean weekly values over a two-month period; (2) large variations in nitrogen due to the immediate effects of irrigation usually occur rapidly and tend to return to the original concentration after irrigation; (3) because irrigation is generally repeated every 10 to 15 days for most crops, weekly samples tend to show nutrient levels before, after, and during irrigation; and

(4) changes in flow and resulting changes in nutrient concentrations due to irrigation are not always abrupt because of the number of days required to irrigate a given field.

Monthly Variations in Individual Systems. Monthly variations of nutrient concentrations were observed in every tile system investigated. The direction, magnitude, and frequency of nutrient variability differed between tile systems and seemed to depend mainly upon irrigation management and field location. Many tile drain flows fluctuated widely, which grossly affected the nutrient concentrations; others had sustained flows (flooded conditions) that caused a prolonged reduction in the nutrient concentrations.

The many variable conditions affecting flows and nutrient concentrations meant that results for an individual system cannot be considered typical of a given number of tile systems or representative of a large area. However, examples presented in Figures 10 and 11 do serve to illustrate the monthly and seasonal variability of tile discharge, nutrients and TDS concentrations in individual systems where irrigation practices differ.

Monthly Variations in Composited Drainage. Monthly variations of nutrients in the drainage composited from the entire study area show a definite trend in relation to the seasons.

Nutrient concentrations in drainage varied greatly between individual tile systems in the study area and appeared to decline in many tile systems during the summer months. In drainage composited from the entire Valley, nutrient concentrations declined appreciably during the peak irrigation season. The magnitude of seasonal variability is illustrated in Figure 12. Nutrient and TDS concentrations are flow-weighted monthly averages based on a two-year period of study (1967-68). Figure 12 shows that concentrations of nitrogen, phosphorus and total dissolved solids varied monthly and inversely with the tile discharge. Twofold variations of both nitrogen and phosphorus were apparent in the drainage from winter to summer. The highest concentration of total dissolved solids occurred in April and the lowest in August. The average TDS varied about 1,000 mg/l from spring to summer, a change that was not as spectacular as the changes in the nutrients.

A fourfold increase was noted in the average discharge from winter to summer.

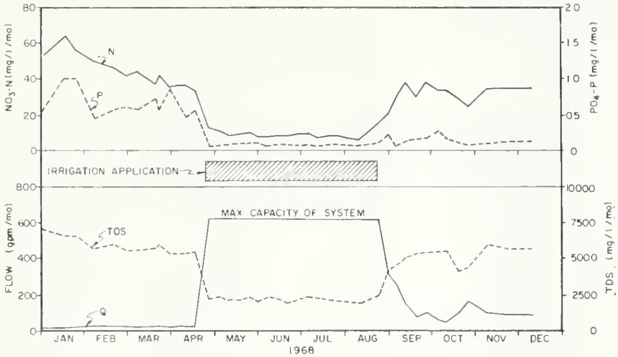

FIGURE 10-VARIABILITY OF FLOW, NUTRIENTS, AND TOTAL DISSOLVED SOLIDS FROM A FLOODED TILE DRAINAGE SYSTEM

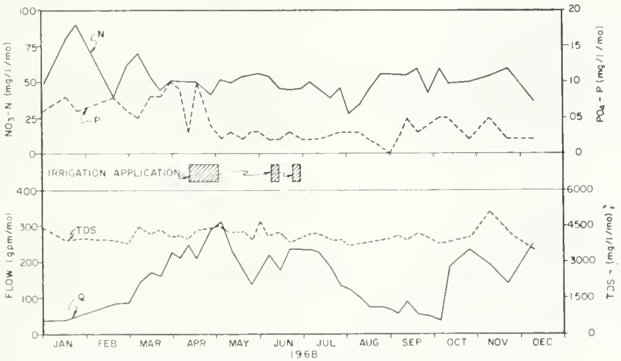

FIGURE 11-VARIABILITY OF FLOW, NUTRIENTS, AND TOTAL DISSOLVED SOLIDS FROM A PERIODICALLY IRRIGATED TILE DRAINAGE SYSTEM

Areal Variability

Nutrient concentrations and flows were found to vary according to the location of individual systems and also in drainage composited according to major tiled areas.

Individual Systems

Reconnaissance investigations conducted in 1966 led to the discovery of wide differences in flows and nutrient concentrations between tile drainage systems within major tiled areas and between major tiled areas. Nitrogen concentrations ranged from 2 to 400 mg/l in drainage collected from individual tile systems over the entire area; phosphorous concentrations ranged from 0.01 to 6.6 mg/l. Tile flows ranged from no flow to more than 1,600 gallons per minute during summer months. Samples collected from individual systems ranged in TDS from 1,320 to 14,630 mg/l in a given month. Most systems in the central area discharged effluent with TDS concentrations exceeding 3,500 mg/l. Several samples collected from an experimental tile system in the San Luis Unit Service Area exceeded 100,000 mg/l at low flow.

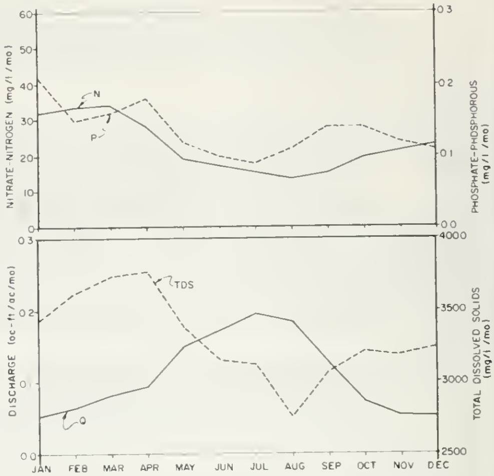

FIGURE 12 - SEASONAL VARIATIONS OF DISCHARGE, NUTRIENT CONCENTRATIONS, AND TOTAL DISSOLVED SOLIDS

Composited Drainage

The variability of discharge, nutrients, and TDS in composited drainage from major tiled areas was much less than that observed in individual systems.

Tile Drain Discharge. Discharges varied between major areas. The highest discharges were noted in the Byron-Westley area, which for the 1967-68 period averaged 2.3 acre-feet per year (Table 11). This amounts to more than twice that of the Gustine-Mendota area, which had the next highest quantity of discharge.

Nitrogen. Nitrogen content in the composited drainage from the central area averaged three times more than in drainage from any other major tiled areas. The average nitrogen value was 32.8 mg/l. (A value of 21 mg/l had been predicted for the entire Valley.) The higher nitrogen concentrations in the tile discharge from the central area greatly influenced the overall nitrogen concentration in the composited drainage of the Valley. However, the low nitrogen

TABLE 11

AVERAGE DISCHARGE, NUTRIENT CONCENTRATIONS, AND TOTAL DISSOLVED SOLIDS BY MAJOR TILED AREAS 1967 AND 1968

Major Tiled Areas	Discharge (ac-ft/ac)	Nitrate-Nitrogen (mg/l)	Phosphate-Phosphorus (mg/l)	Total Dissolved Solids (mg/l)
Byron-Westley	2.3	8.5	0.09	2,170
Westley-Gustine	0.69	9.0	0.06	2,740
Gustine-Mendota	1.12	32.8	0.07	4,130
Tulare Lake	0.57	9.6	0.69	3,760

content of drainage from systems in the northern and southern areas tends to dilute the high nitrogen level that might otherwise occur in drainage from the entire study area.

Phosphorus. In drainage composited by different areas, phosphorus was found in much lower concentrations than was nitrogen. The highest concentrations were observed in drainage from the southern area (Tulare Lake). Phosphorous concentrations there averaged 0.69 mg/l, about seven times higher than any other area.

Total Dissolved Solids. Drainage from the Gustine-Mendota area was the highest in TDS concentrations. TDS concentrations in the composited drainage from the Byron-Westley and Westley-Gustine areas were about 1,000 mg/l lower than the drainage from the other two areas. The difference in the average TDS in drainage between the Gustine-Mendota and Tulare Lake areas was small.

Variability Due to Agricultural Practices

Tile drainage flow as well as nutrient concentrations are generally affected by certain agricultural practices. Irrigation, cropping, and fertilization practices and their effects upon tile drainage are discussed in this subsection.

Influence of Crops on Tile Discharge

Certain heavily irrigated crops directly influence flows in tile drainage systems. When irrigated, rice, alfalfa, and cotton crops produced almost immediate increases in drainage response and, at times, sustained high flows. Rice, for example, is flooded from early June through August. Although other factors such as the amount of vegetative ground cover, plant conditions, stage of growth, soil conditions, and other factors have been known to affect the amount of effluent discharged, irrigation intensity was considered the most important single factor. Table 12 presents the annual average tile discharge for various crops in 1959-63 and 1967. Several tile systems are represented for each crop shown.

TABLE 12

COMPARISON OF
TILE DRAIN DISCHARGE BY VARIOUS CROPS
(in acre-feet per acre)

Major Crop	Discharge (Acre-Feet per Acre)					
	1959-63			1967		
	Max.	Min.	Avg.	Max.	Min.	Avg.
Rice	4.2	0.5	1.3	2.0	0.7	1.4
Cotton	1.0	0.2	0.5	3.0	0.5	1.1
Alfalfa	C.2	0.2	0.2	17.3	0.3	3.1
Beets	0.9	0.7	0.8	1.5	0.1	1.0
Beans	--	--	--	2.0	1.0	1.3
Pasture	0.9	0.7	0.8	--	--	--
Orchards	--	--	--	0.8	0.4	0.7
Safflower	--	--	--	2.0	0.7	1.4
Barley	1.3	0.1	0.5	0.7	0.3	0.3
Fallow	1.1	0.3	0.6	--	--	--
General Field Crops	0.7	0.4	0.5	--	--	--

The kind of crop does not always dictate the quantity of tile drainage. Several other tile systems (not shown in Table 12) draining diversified row crops within the study area discharged more per year than did the systems from tiled rice fields.

Influence of Crops on Nitrogen Concentrations

Rice was the only crop that exerted an appreciable influence on nitrogen concentrations observed in tile drainage systems. The decreased nitrogen concentrations noted in effluent discharged from rice fields were possibly due to a combination of two interrelated factors. Dilution, which is a physical lowering of nutrient levels resulting from irrigation, and denitrification, which involves nitrogen losses that are promoted by anaerobic soil conditions, are probably the main reasons for the low nitrogen levels. In some cases tile drainage from flooded rice fields in the Gustine-Mendota area showed mid-summer decreases in nitrogen to less than one-third their wintertime concentrations. One tiled field in particular dropped from a January level of 63 mg/l to 7 mg/l for the months of May, June, and July.

The average annual nitrogen concentration in the combined drainage from all rice fields, which for this study was limited to the Gustine-Mendota area, was 10.9 mg/l. The average concentration for all other tile-drained crops investigated in the same area was 43.7 mg/l.

Irrigation Influence on Discharges

The influence of crops upon tile drainage flow without regard to the quantities of irrigation water applied has already been discussed in the foregoing subsection. Actual applied water was determined only for a few tile systems during the initial investigations. Because of the large number of tile systems being sampled and the complexity of irrigation practices on many large tiled fields, measurements were not made during the more intensive investigations. However, headgate irrigation requirements (10), the quantities of water required in the growth of crops exclusive of rainfall, are very nearly the same for many crops in the different major tiled areas. The quantity of tile discharge compared to the irrigation intensity (determined from headgate irrigation requirements) within the major tiled areas is presented in Table 13.

Irrigation Influence on Nitrogen Concentrations

Although the type of crop grown usually determines the relative amounts of water required, overirrigation and, to a lesser extent, underirrigation can greatly affect the quantity and nutrient quality of tile drainage. Low nutrient concentrations seemed to be associated with flooded soil conditions; denitrification and dilution were suspected. Heavy irrigations may also add nitrogen to the soil.

Individual Systems. The influence of irrigation upon nutrient concentrations in individual systems varied greatly. In many but not all systems, nitrogen concentrations varied

TABLE 13

TILE DRAIN DISCHARGE VS. IRRIGATION INTENSITY WITHIN MAJOR TILED AREAS 1967

Irrigation Intensity[1/]	Average Tile Discharge (ac-ft/ac)			
	Byron-Westley	Westley-Gustine	Gustine-Mendota	Tulare Lake
Light (0.0-0.9)	2/	2/	.7	.6
Medium (1.0-2.9)	2.2	1.1	1.1	.6
Heavy (3.0-3.9)	2.2	.5	1.0	1.2
Very Heavy (4.0-8.0)	.8	2/	.4	.5
Flooded	2/	2/	.8	2/

1/ Arbitrary categories based on headgate irrigation requirements of crops, weighted by acres.

2/ No tiles within the irrigation intensity categories.

inversely with tile flow. Several tile systems located in the northern area had nutrient concentrations that remained rather constant throughout the study period. However, nitrogen was observed to increase with increases in tile discharge from several individual tile systems within the study area.

Denitrification. The variability of nitrogen in drainage from certain tile systems may have been due to denitrification which has already been mentioned in regard to crops that were flooded. However, low nitrogen concentrations were found in drainage from tiled areas that were not flooded. Although investigations were not conducted to determine if the seasonal decrease in nitrogen concentrations was actually due to denitrification, findings by other investigators show that under certain conditions denitrification does take place. Ponnamperuma (16) reports that no more than 3 mg/l nitrate had ever been reported in the soil solution of a flooded soil following irrigation and that nitrogen losses are due chiefly to the reduction of nitrate to the oxides of nitrogen or nitrogen gas. Ponnamperuma concludes that nitrate is not a suitable fertilizer for rice because of denitrification and leaching losses. Power (17) reports bacterial denitrification losses may account for a major part of fertilizer nitrogen applied in lands with poor drainage. Meek, et al (18), found significant decreases of nitrogen in saturated fine-textured soils which were fertilized under a laboratory-controlled environment.

Nitrogen losses and the production of nitrogen gas corresponded to increases in soil moisture above 41 percent. He also found that nitrogen losses in tile drainage from the field only amounted to 1.5 percent of the 246 pounds per acre applied. Decreases in nitrate were associated with increases in depth and proximity of the water table. Investigations conducted by the then Federal Water Quality Administration (FWQA) in cooperation with the Department of Water Resources showed similar denitrification in saturated Panoche loam and Tulare loam soils of 0.54 percent and 0.62 percent per hour, respectively.

In several tile systems investigated for dissolved oxygen, the lowest concentrations were observed in drainage from rice fields. Fields having more than one crop had the highest levels, followed by fields in which cotton and beans were grown. Ranges and averages are presented in Table 14.

TABLE 14

DISSOLVED OXYGEN CONCENTRATIONS IN TILE DRAINAGE FROM VARIOUS CROPS

Crop	Number of Systems	Dissolved Oxygen (ppm)		
		Maximum	Minimum	Average
Rice	3	1.8	.7	1.4
Fallow	1	1.6	1.6	1.6
Alfalfa	3	3.5	3.2	3.4
Beans	4	6.0	2.4	4.4
Cotton	5	7.9	1.5	4.9
Diversified	9	7.8	0.9	6.1

Dilution. Dilution was also mentioned as a cause of low nitrogen in heavily irrigated crops. The decrease in nitrogen due to dilution is somewhat substantiated in that nitrogen levels are the lowest during peak irrigation and nearly always approach the preirrigation concentrations. Also, TDS levels decreased simultaneously with nitrogen concentrations in drainage from many individual systems where discharges remained high in the summer months. Figures 10 and 11 illustrate the reactions of TDS to irrigation and their correlations to nutrients. A decrease in TDS and nutrients (nitrogen and phosphorus) along with an increase in discharge was observed in the composited drainage from the entire study area (Figure 12). This decrease is presumed to be caused partly by dilution and partly by denitrification. The mid-summer decline of nutrients in the composited drainage cannot be attributed solely to the influence of drainage from rice fields. Similar decreases in nutrient and TDS concentrations also occurred in composited drainage from the central area when rice field data were eliminated.

Nitrogen in Irrigation Water. One important aspect of irrigation is the amount of nutrients added during application. Nitrogen in irrigation water is usually found in the nitrate form; organic nitrogen is nearly always found to be less than 1 mg/l. The nitrate form of nitrogen is readily suitable for uptake by most plants, although the ammonium ion can be assimilated by some crops. However, more than an acre-foot of water is applied to fields for preirrigation, when no crop is being grown, and during early stages of growth when the root development is not great, which could result in losses to the ground water. Lysimeter studies (19) have shown exceptionally high leaching losses when soils are fallow. Nitrate-nitrogen concentrations in irrigation water applied to tiled fields in the study area were determined to be 4.0 mg/l, which amounts to approximately 11 pounds of nitrogen added for every acre-foot of irrigation water applied. Nitrogen contributed in this manner could exceed 40 pounds per acre for certain heavily irrigated crops for even one year, discounting other possible losses.

For this investigation, nitrogen contributed to the soil in applied water or rainfall was assumed to be about the same in all areas, considering crop diversification and water requirements of such large areas. Gains in nitrogen due to irrigation application were considered more than "offset" by the amounts lost due to deep percolation, volatilization, and denitrification.

Fertilization

Much has been written regarding the leaching of nitrogen from soils. However, data to show the contribution of fertilizer nitrogen to shallow ground water are scarce. Although specific studies were not conducted to determine the actual amounts leaching to the water table, agricultural data showing the amounts of nitrogen fertilizer applied in major tiled areas over a long period are discussed in relation to to the concentrations of nitrogen observed in the drainage. Leaching of fertilizers is also discussed in the subsection that follows.

Leaching. Lysimeter investigations (19) have shown that the amount of nitrogen leached through soils during irrigation is quite dependent upon the amount of nitrogen present or added, its form, the soil texture, the type of crop, and the maturity of the crop. Dyer, et al (20), showed evidence of nitrate leaching due to irrigation in comparisons of irrigated and nonirrigated profiles of Panoche soils on the west side of the San Joaquin Valley. Johnston, et al (21), concluded that nitrogen and phosphorous levels in drainage from west side tile systems correlated with fertilizer application. However, as many or possibly even more investigations have shown that leaching of applied fertilizers is negligible under certain conditions. Williford and Tucker (22) reported very low recovery of tagged fertilizer (N_{15}) in leachate collected from a series of lysimeters filled with fine-textured west side soils which were cropped, heavily fertilized, and irrigated routinely. The highest percentage recovered was in leachate collected from Panoche fine sandy loam, which was only 3.58 percent of the total applied. Bower and Wilcox (23) reported that nitrogen failed to increase in the upper Rio Grande from drainage influence of three highly fertilized adjacent areas. In this case, records of fertilization showed an increase from a very low to a very high level over a 30-year period. The absence of nitrates in the drainage was attributed more to denitrification promoted by anaerobic conditions than to the possibility of no significant leaching below the root zone.

Applied Nitrogen Versus Discharged Nitrogen. In several cases, the nitrogen concentrations observed in tile drainage from individual systems seemed to correlate with the amounts of fertilizers applied. However, high rates of fertilization were recorded for many tiled fields having low levels of nitrogen in the drainage. Fertilizer records obtained over a ten-year period are compared in Table 15 to the average nitrogen concentrations observed in subsurface waters discharged from major tiled areas. The yield of nitrogen per acre was also determined for comparison to the average fertilization rates. For the most part, no direct correlations could be made during this study between the quantity of nitrogen fertilizer applied and the concentrations of nutrients in tile drainage. Only in the Gustine-Mendota area did there appear to be a general relationship between the two factors. Here the heaviest nitrogen fertilization occurred and the greatest amount of nitrogen was discharged. However, rather heavy applications of fertilizer were also made in the Tulare Lake and Byron-Westley areas for at least ten years with no appreciable effect on the nitrogen concentrations observed in the drainage. Also, fertilizer application for certain individual tiled fields was much higher than the average fertilization rates indicate; however, nitrogen concentrations still remained about 10 mg/l. The relatively low concentrations in the drainage from these areas show that nitrogen does not accumulate over long periods in the subsurface waters. The yield of nitrogen from the Gustine-Mendota area in 1967 was nearly as great as that applied for the same year. Although there was more yield from this area during 1968, this resulted primarily from an increase in the total discharge, rather than increases in the nitrogen concentrations. The data show that nitrogen concentrations were actually lower for 1968 than 1967. Although fertilizer data were not collected for 1968, it is doubtful that the increase in yield could have been due to increased fertilization of a large number of the tile systems in the area.

TABLE 15

APPLIED NITROGEN VS. DISCHARGED NITROGEN BY MAJOR TILED AREAS

Major Tiled Area	Quantity of Nitrogen Fertilizer Applied (avg lbs/acre/year)			Average Discharged Nitrogen			
				1967		1968	
	1957-67	1962-67	1967	Yield (lbs/acre)	Conc. (mg/l)	Yield (lbs/acre)	Conc. (mg/l)
Byron-Westley	50	61	72	40 1/	7.4 1/	68	9.2
Westley-Gustine	33	44	67	14	7.5	21	10.4
Gustine-Mendota	88	75	92	85	34.6	112	31.8
Tulare Lake	74	68	43	19	10.5	12	8.7

1/ Partial year's data (seven months).

The yield from the Byron-Westley area increased significantly in 1968 over 1967 because of a longer sampling period.

<u>Phosphorous Fertilization</u>. Phosphate fertilizers were found to be applied less frequently than nitrogen fertilizers in all major tiled areas. Accurate records were not kept on most farms. Application rates were only obtained from one large operation in the Tulare Lake area. Records showed that phosphate fertilizer was applied regularly at the rate of 50 pounds per acre every other year. Phosphate concentrations in tile drainage from that area seemed to indicate a relation between application and discharge. Soil investigations (24) conducted by the Department of Water Resources have shown that an association may exist between shell fragments in the soil of the Tulare Lake soil series and the extraordinary phosphorous content in the tile drainage. Shell fragments removed from the soil profiles contained

0.11 percent phosphorus pentoxide by weight. Laboratory tests indicate that the shell fragments contained from 0.12 to 0.15 percent phosphate. Also, during the investigation the odor of hydrogen sulfide gas was detected in several augered holes where high water table conditions existed. Anaerobic conditions, indicated by the presence of the hydrogen sulfide gas, in effect lower the soil pH which results in acidic conditions within the soil and a consequent release of phosphates (25).

Variability Due to Physiography

An apparent association between quantity and quality of the tile drainage and the physiographic positions of the drain systems led to an investigation of this aspect of tile drainage. As already pointed out, fertilizer application rates did not always correlate with the concentrations observed or pounds of nitrogen discharged in tile drainage. During the course of the study, it became evident that certain tile drainage systems occupying alluvial fan positions discharged effluent containing high concentrations of nitrogen, whereas systems located in the basin rim and basin position generally had lower nitrogen concentrations.

Discharge

The highest average discharges were derived from tile systems located in the older alluvial fan positions. Several systems in the northern area with exceptionally high flows were so located. Although these systems discharged greater quantities of effluent than did tile drains located in other major tiled areas, they were typical of other drains not being sampled in that area. Several individual drains located on older alluvial fans of the central area also had high discharges.

Nutrients and Total Dissolved Solids

The composited drainage from tile systems within basin and basin rim positions was significantly lower in nitrogen than that from alluvial fans.

Phosphorus was six times more concentrated in the drainage from tile systems occupying basin positions than other positions.

Composited drainage from tiles located in the basin rim position was the highest in TDS, followed by the basin position.

The weighted average flow, nutrient concentrations, and TDS in composited drainage from the systems monitored in the entire area over a two-year period (1967-68) are summarized by physiographic positions in Table 16.

TABLE 16

TILE DRAIN DISCHARGE, NUTRIENT CONCENTRATIONS, AND TOTAL DISSOLVED SOLIDS SUMMARIZED BY PHYSIOGRAPHIC POSITIONS 1967-68

Physiographic Positions	Weighted Average Values			
	Flow (ac-ft/ac)	NO_3-N (mg/l)	PO_4-P (mg/l)	TDS (mg/l)
Recent Alluvial Fan	1.1	26	0.09	3,160
Older Alluvial Fan	1.8	15	0.08	2,500
Basin Rim	1.2	11	0.09	4,410
Basin	0.7	10	0.60	3,450
Weighted Summation	1.3	19	0.13	3,160

Variability Due to Soils

Differences between nutrient concentrations and quantities discharged were recognized in tile drains from similar physiographic positions. These inconsistencies led to an examination of soil series as a criterion for determining quantity and quality of tile drainage (Table 17).

Discharge

The highest quantity discharged was from one system located in Ambrose soil series. Drainage from this system exceeded 17 acre-feet per acre per year in 1968. The next highest discharge was from a tile system located in the Rincon soil

TABLE 17

AVERAGE TILE DRAIN DISCHARGE, NUTRIENT CONCENTRATIONS, AND TOTAL DISSOLVED SOLIDS FROM DIFFERENT SOIL SERIES AND PHYSIOGRAPHIC POSITIONS

Physiographic Position	Soil Series	Number of Systems	Estimated Acres	Discharge (ac-ft/ac/yr)	NO_3-N (mg/l)	PO_4-P (mg/l)	TDS 1/ (mg/l)
Recent Alluvial Fan	Panoche	8	2,071	0.8	38	0.08	3,720
	Sorrento	6	2,356	1.9	11	0.08	2,460
	Panhill	4	595	2.3	45	0.05	3,880
	Foster	1	73	0.9	16	0.82	2,070
Older Alluvial Fan	Rincon	4	895	2.0	8	0.08	2,290
	Ambrose	3	169	6.9	7	0.08	3,580
	Lost Hills	3	858	1.1	54	0.07	4,930
Basin Rim	Oxalis	4	825	1.9	10	0.08	4,470
	Lethent	2	390	1.1	20	0.05	4,960
	Willows	1	140	1.0	4	0.08	5,430
Basin	Tulare	4	1,080	0.5	7	0.63	5,640
	Sacramento	1	73	2.1	5	0.26	2,030
	Hacienda	1	120	1.1	15	0.88	3,700

1/ Total Dissolved Solids

series. The total discharge from this system was in excess of 8.0 acre-feet per acre for 1968. Drainage from these and a few other tile drainage systems in the study area represents systems where more water was discharged than applied during the irrigation season.

Movement of subsurface water into tile systems from outside influences (lateral movement from other irrigated areas, canals, and other sources of water) was suspected in many tile drains when discharges continued after irrigation had ceased. Although lateral movement was apparent in several tile drainage systems throughout the study area, none were as obvious as the two just mentioned.

Tile drainage discharge expressed as acre-feet per acre depends entirely upon one's interpretation of the acreage actually drained. Contributions of subsurface drainage from outside influence were impossible to quantify. Therefore, any attempt to use the foregoing data to predict drainage from a small area would be erroneous. However, discharges representing several tile systems within a given soil series (Table 17) might be used for predicting drainage from an extensive area where soil conditions are similar. For instance, tile systems in the Tulare Lake area discharge low volumes of effluent. Further installations in this area can reasonably be expected to do the same. Accordingly, other discharge values given for specific soils under similar soil conditions might be applicable.

Nutrients

When drainage from tile systems occupying similar soil series and physiographic positions was composited, the highest nitrogen concentration was shown to occur in the drainage from the Lost Hills soil series (older alluvial fan). Drainage from related Panoche and Panhill soils (recent fans) was the next highest in nitrogen concentration. These three soils represent large alluvial fans along the west side from Mendota to south of Bakersfield. Tile drainage from tile systems located in Sorrento and Rincon soils was found to be low in nitrogen. These soils also represent substantial acreages of recent and older alluvial fans, respectively, within the northern area.

Drainage composited from tile systems situated in Oxalis and Tulare soils, which comprise the largest acreage of the basin rim and basin positions, respectively, was rather low in nitrogen. The lowest nitrogen level (4.0 mg/l) was found in drainage from a single tile system in the Willows soil series.

Relatively high concentrations of phosphorus were observed in the drainage from all of the soil series near Tulare Lake. Foster and Hacienda were slightly higher in phosphorus than was the Tulare series.

From these comparisons, high nitrogen concentrations in drainage composited from San Joaquin Valley tile systems were found to be associated mainly with Panoche and related soil series located in the Gustine-Mendota area. Tile drains in this area are expected to contribute approximately 36 percent of the total drainage from the Valley by the year 2020, and because nitrogen concentrations are significantly higher in the drainage from this area compared to other major tiled areas, the seasonal impact upon a drainage facility becomes important.

Figure 13 compares the monthly average nitrogen concentrations in drainage composited from three groups of soil series: the Panoche group (Panoche, Panhill and Lost Hills); the Sorrento group (Sorrento, Rincon, and Ambrose); and the Basin group (Oxalis, Lethent, and Tulare). The Panoche group occurs in the Gustine-Mendota area, and the Sorrento group occurs in the Byron-Westley area. The Basin group, which is not a family grouping, represents the composited drainage from basin and basin rim soil series within all the major tiled areas. It is shown to illustrate the seasonal variation in drainage having low nitrogen concentrations and for comparison to the family groups. Although the Panoche and Sorrento family groups are similar in texture, soil development, and other factors, they do differ genetically. The greatest seasonal variation of nitrogen occurred in the drainage from the Panoche grouping.

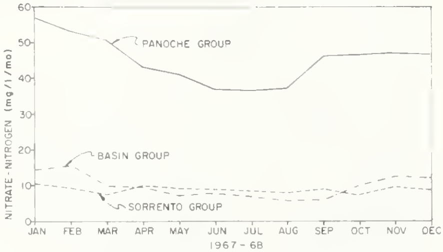

FIGURE 13-SEASONAL VARIATION OF NITROGEN CONCENTRATIONS IN DIFFERENT GROUPINGS OF SOILS

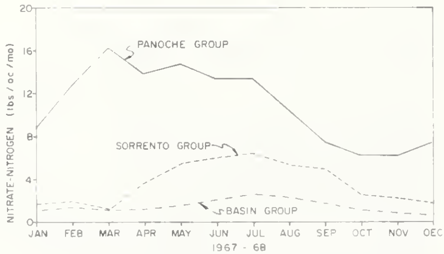

FIGURE 14-SEASONAL DISTRIBUTION OF NITROGEN YIELD IN DIFFERENT GROUPINGS OF SOILS

The yield of nitrogen (pounds per acre per month) from tile systems within the soil groupings is presented in Figure 14. The greatest nitrogen yield occurred in drainage composited from the Panoche group; peak yield occurred in March, which was possibly the result of early leaching during preirrigation. The influence of relatively high discharge along with low nitrogen concentrations is shown in the contrasting yield of nitrogen between the Sorrento group and that of the Basin group. Several tile systems having the highest discharges were associated with the Sorrento and related soils.

Total Dissolved Solids

Table 17 also shows that average concentrations of total dissolved solids were the highest in drainage from tile systems in the Tulare (basin position) and Willows (basin rim position) soil series, which are among the lowest in nitrogen.

Drainage Site Classes

To determine reasonable permeabilities for different soils, the Department of Water Resources mapped west side soils and classified them by drainage site classes. This classification scheme was based on the physiographic positions defined earlier, on soil profile texture, and on stratigraphy. These drainage classes permit more exact descriptions of the ability of a given soil to transmit water both vertically and horizontally.

Drainage from tile systems within each drainage site class was composited and averaged to determine the relative discharge and nutrients for a particular grouping. A map designating the locations of some of the drainage site classes mapped along the west side is shown in Figure 15. Meanings of symbols used in the delineations are presented in Table 18. The acreage of tile systems sampled within each class is presented in Table 19 along with the average discharge and concentrations of nitrogen, phosphorus, and total dissolved solids. The drainage site classes are presented in their order of decreasing permeability.

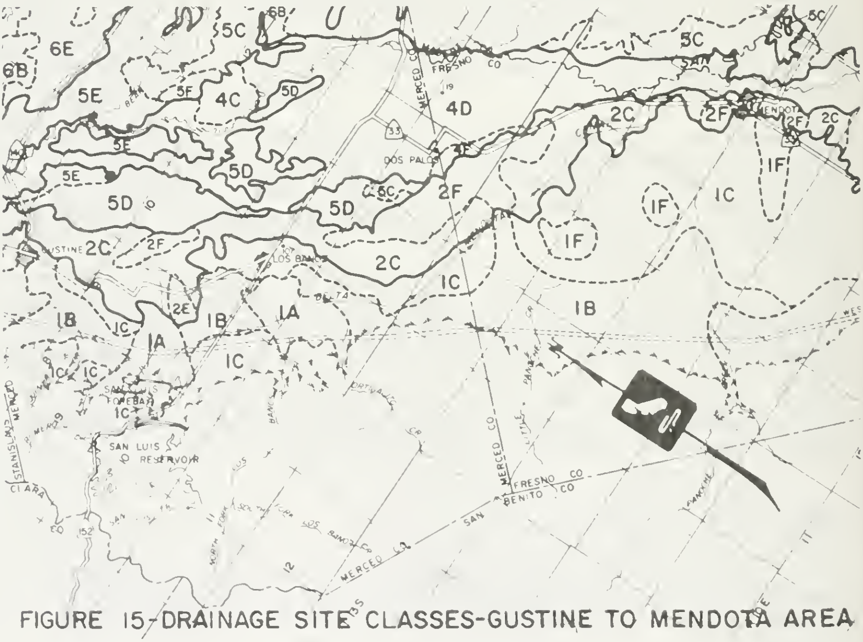

FIGURE 15-DRAINAGE SITE CLASSES-GUSTINE TO MENDOTA AREA

TABLE 18

MEANINGS OF MAP SYMBOLS USED FOR
DESIGNATING DRAINAGE SITE CLASSES

NUMBERS (Physiographic Positions)	LETTERS (Soil Permeability Profile Groups)
1 - Alluvial fans on the west side of the Valley, chiefly from sedimentary sources.	A - Moderate to rapid permeability throughout without a significant restricting horizon.
2 - Basin rim west of the trough. Alluvium from sedimentary sources.	B - Moderate to rapid permeability to depths ranging from 8 to 15 feet underlain by a very slowly permeable horizon beneath which may be strata of varying permeabilities.
3[1/]- Overflow deposits of coarse and medium texture, adjacent major channels in the valley trough.	C - Dominantly fine-textured surface profile or one having moderate development, underlain by stratified alluvium with combinations of slowly permeable horizons and moderately to rapidly permeable strata which will allow relatively free lateral movement of significant volumes of water.
4 - Trough and basin areas which are the lowest positions in the Valley.	D - Fine-textured, slowly permeable surface material, varying from approximately 4 to 8 feet in depth, underlain by thick strata of moderately to rapidly permeable alluvium, often deep deposits of loose channel sand.
5 - Basin rim east of trough. Alluvium chiefly from granitic sources.	E - Strongly developed (claypan and hardpan) soils or those having a slowly permeable unrelated substratum (the claypan, hardpan, or substratum within 60 inches of the surface), underlain by a combination of slowly permeable horizons and moderately to rapidly permeable strata.
7 - Low anticlinal ridges.	F - Mainly fine-textured alluvium with tendency toward increasing density and degree of compaction with depth. May include some thick strata of rapid to moderate permeability which do not provide space for a significant volume of water, and often pinch out within the body of fine material.

1/ Does not occur in the Drainage Site Classes in Figure 15.

TABLE 19

AVERAGE TILE DRAIN DISCHARGE, NUTRIENT CONCENTRATIONS AND TOTAL DISSOLVED SOLIDS ACCORDING TO DRAINAGE SITE CLASSES 1968

Drainage Site Class	Number of Drains	Estimated Tiled Acreage	Discharge (ac-ft/ac/yr)	Nutrients (mg/l)		TDS (mg/l)
				NO_3-N	PO_4-P	
1B	2	870	0.84	32.7	0.05	5,080
6B	1	73	0.87	15.8	0.82	2,070
1C	23	4,883	1.66	24.9	0.07	3,220
2C	5	1,528	1.44	10.8	0.07	3,390
4C	5	1,213	0.56	7.7	0.59	3,290
4D	1	209	0.98	11.1	0.05	1,860
5D	1	60	0.32	5.2	2.01	7,280
1F	2	588	1.68	9.3	0.05	2,890
2F	2	221	1.80	5.1	0.07	3,060

The highest discharge according to drainage site classes occurred in the 1F and 2F classes, which according to the classification are fine-textured alluvium with dense compact subsoils. These soils which by definition are supposed to be slowly permeable are greatly influenced by surrounding high water table conditions. They are represented by two tile systems in each class. The next highest average discharge came from drains located in the 1C and 2C classifications, which are located in alluvial and basin rim soils with stratified profiles that allow free lateral movement of water. These last two categories are among the few that are well represented by tiled acreage. The drainage from these classes is considered to be more in line with the quantities expected from highly permeable soils having few restrictions in the subsoil.

Nutrient concentrations were the highest in drainage composited from the 1B and 1C classifications, which represented most of the tiled alluvial soils within the study area, and phosphorus was the highest in the 5D class.

This system of classification, along with additional field exploration, further correlation to tile discharges and nutrient concentrations, could possibly be used to project discharges and nutrient concentrations from areas that are to be tile-drained in the future.

Residual Nitrogen in West Side Soils

Background

The presence of nitrogen was investigated in various soil profiles along the west side of the San Joaquin Valley floor, and these findings correlated rather well with concentrations of nitrogen observed in tile drainage discharge of similar soils. The following points were the basis of such correlation.

1. Nitrogen concentrations in tile drainage from alluvial soils were higher than in drainage from other physiographic positions investigated; in many cases, nitrogen yields exceeded fertilizer applications.

2. Findings by other investigators presented strong evidence of native or residual nitrogen in certain soils.

This phenomenon was first reported by Dyer (20), whose data showed that nitrogen concentrations lying as deep as 25 to 50 feet in a virgin Panoche soil near the Coast Range foothills exceeded 1,400 milligrams per liter. Doneen (26) observed high nitrates in shallow ground water in irrigated Panoche and Oxalis soils. Later, Doneen, et al (27), in an economic study on the potential agricultural development of new lands in the southwest San Joaquin Valley, again observed high nitrate-nitrogen levels in virgin Panoche and Panhill soils. Deep boring investigations (15) conducted by the Agricultural Research Service showed moderate to high nitrate values at depths of 20 to 60 feet in west side Panoche soils which were farmed. Nitrate values in Hesperia and Tujunga soils, which are located on the east side of the Valley, were significantly lower in nitrates at greater depths (Figure 16). Three tile drainage systems located along the east side of the Valley, but in different locations than the plots mentioned above, also showed evidence of low nitrogen concentrations. These systems, which were not actually included in the regular nutrient monitoring program, were monitored periodically from June through December 1967; the combined drainage averaged 10 mg/l nitrate-nitrogen. Quantities of nitrate in terms of pounds above the water table were determined at separate borings for each plot. The data are illustrated in Figures 17 and 18. From these investigations, the ARS determined that fertilizer application could not possibly account for the large amounts of nitrates found in the west side Panoche profiles.

These independent observations of nitrates in soils were a prelude to investigations of residual soil nitrogen initiated by the Department of Water Resources. Soil profiles

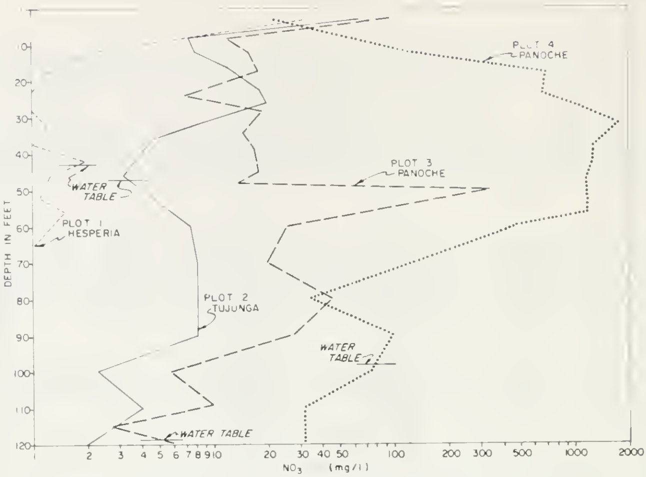

FIGURE 16 - NITRATE CONCENTRATIONS WITHIN DEEP PROFILES OF EAST AND WEST SIDE SOILS

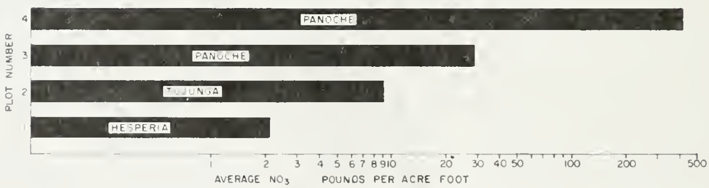

FIGURE 17 - QUANTITIES OF NITRATE IN DEEP PROFILES OF EAST AND WEST SIDE SOILS

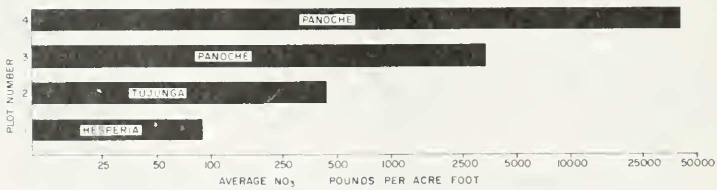

FIGURE 18 - QUANTITIES OF NITRATE ABOVE THE WATER TABLE IN DEEP PROFILES OF EAST AND WEST SIDE SOILS

representing the major soil series and physiographic positions were sampled in an area extending from Tracy south along the west side to Lost Hills. Forty-five sites were sampled to a depth of 10 feet or more; samples were collected at incremental depths not exceeding 3 feet. Virgin sites were sought to obtain the quantity of nitrogen in the soil before irrigation. Several dry-farmed and irrigated sites were also sampled.

Ranges and Magnitudes

Nitrogen concentrations within individual profiles varied considerably between sites and with depth; leaching was apparent at the surface of nearly all virgin profiles sampled.

Table 20 is a virgin profile of the Panhill series and is an example of the variability of nitrogen by depth. The distribution of nitrogen throughout the profile is typical of similar virgin sites and other related soil profiles investigated in the area. As the example shows, nitrogen in the first foot or more has been leached. An inverse condition was found for many irrigated soils which were fertilized. Therefore, for this study only the samples from 3 to 10 feet were considered representative of nitrogen in the tile zone. (Tile laterals are normally installed at depths between 6 and 9 feet.) This was done to make the most accurate assessment of the average nitrogen conditions in the soil profile.

TABLE 20

EXTRACT ANALYSIS OF A VIRGIN ALLUVIAL SOIL ON THE WEST SIDE OF THE SAN JOAQUIN VALLEY

Site	Depth Range	Texture	Saturation Percentage	$EC \times 10^6$ of Extract	NO_3-N (mg/l)
N-6 (Panhill Series)	0 - 1.5	loam	42.8	515	18.0
	2.5 - 4.0	sandy clay loam	43.6	5,270	83.5
	4.8 - 5.7	fine sandy loam	32.8	6,575	257.0
	6.5 - 8.2	loam	37.6	6,240	242.0
	9.2 -10.4	fine sandy loam	32.6	5,985	208.0

Nitrogen concentrations were averaged (depth-weighted) and grouped by soil series and site conditions. All irrigated sites were assumed to have been fertilized; dry-farmed sites were counted as receiving minimum fertilization and were therefore combined with virgin sites of the same soil series in the analysis. When interfan areas were so noted, they were analyzed separately from the main body of alluvial soils in order to determine the extent of natural leaching that took place. The average nitrogen levels for individual sites are given in Table 21.

TABLE 21

AVERAGE[1/] NITROGEN CONCENTRATIONS IN VIRGIN, IRRIGATED, AND DRY FARMED SOIL PROFILES ALONG THE WEST SIDE OF THE SAN JOAQUIN VALLEY

Site Number	Phys.[2/] Position	Series Name	Soil Type[3/]	Nitrogen in Tile Zone (mg/l)	Field Condition Modifiers: Virgin	Irrig.	Fert.	Dry-F.	Field Observation Notes
N-1	BR	Lethent	sc	113		X	X		Restricted permeability.
N-2	BR	Lethent	sc	171		X	X		Restricted permeability.
N-3	RA	Panhill	sl	167	X				Relatively unleached.
N-4	RA	Panhill	sl	35		X	X		Relatively unleached.
N-5	BR	Lethent	cl	1	X				Main stream course.
N-13	OA	Lost Hills	l	4	X				Main stream course.
N-17	RA	Panoche	l	1	X				Main stream course.
PG	RA	Panoche	l	2	X				Main stream course.
N-8	BR	Volta	scl	1		X			Subject to frequent high water table.
N-9	BR	Orestimba	c	1		X			Subject to frequent high water table.
N-10	BR	Orestimba	cl	1		X			Subject to frequent high water table.
N-11	BR	Rossi	cl	5		X			Subject to frequent high water table.
N-6	RA	Panhill	l	209				X	Interfan area.
N-7	RA	Panhill	l	12	X				Near creek.
N-12	RA	Panhill	l	165				X	Interfan area.
N-14	RA	Panoche	l	234	X				Upper fan area.
N-15	RA	Panoche	l	233	X				Upper fan area.
N-18	RA	Panoche	fsl	27	X				Small fan bottom.
N-16	RA	Panoche	cl	21	X				Close proximity of farmed area.
N-19	RA	Panoche	l	16	X				Close proximity of farmed area.
N-25	RA	Panoche	fsl	47		X	X		Intensively farmed.
N-20	RA	Panoche	sic	8		X	X		Intensively farmed.
N-24	RA	Panoche	sic	8		X	X		Near open drain.
N-28	RA	Panoche	sic	6		X	X		Upslope from open drain.
N-29	RA	Panoche	sic	12		X	X		Upslope from open drain.
N-26	RA	Panoche	sic	80		X	X		Lower end of cotton field.
N-27	RA	Panoche	sic	16		X	X		Near open drain.
N-30	RA	Panoche	sic	25		X	X		Center of field.
N-21	RA	Panoche	sic	94		X	X		
N-22	RA	Panoche	sic	61		X	X		Intensively farmed.
N-23	RA	Panoche	l	49		X	X		Intensively farmed.
N-31	T	Denverton	c	33	X				Sampled on fence line.
N-32	OA	Rincon	cl	15	X				Alluvial bottom.
N-33	T	Los Banos	l	4	X				Terrace soil.
N-34	RA	Panhill	l	8	X				High fan position.
N-35	OA	Lost Hills	l	42	X				High fan position.
N-36	OA	Lost Hills	l	10	X				Coarse textured subsoil.
N-37	OA	Lost Hills	cl	206	X				Near gypsum mines.
N-38	RA	Panhill	fsl	194	X				Near gypsum mines.
N-40	RA	Sorrento	ls	32	X				Near Kettleman Hills.
N-42	OA	Lost Hills	l	3				X	Coarse textured profile.
N-39	OA	Rincon	cl	2				X	Underlain by gravel.
N-43	RA	Ambrose	c	59				X	Deposited by Patterson Creek.
N-41	OA	Zamora	cl	0				X	Deposited by Corral Hollow Creek.
N-44	RA	Sorrento	fsl	17				X	Deposited by Lone Tree Creek.

1/ Average = depth weighted NO_3-N in tile zone (3 - 10 feet).
2/ Physiographic positions: BR = basin rim, RA = recent alluvium fan, OA = older alluvial fan, T = terrace.
3/ Surface texture: sc = sandy clay, sl = sandy loam, cl = clay loam, l = loam, scl = sandy clay loam, fsl = fine sandy loam, sic = silty clay, ls = loamy sand, c = clay.

Variability of Nitrogen from Different Sites

Average nitrogen concentrations within individual profiles of different soil series varied from 0.0 mg/l to 234 mg/l; concentrations exceeding 400 mg/l were observed at depth in some samples. Nitrogen concentrations were found to be higher for virgin than for irrigated soils of the same series. Also, extreme differences in nitrogen concentrations were observed between soils occupying different physiographic positions; interfan areas were higher in nitrogen than was the main body of the alluvial fan.

Virgin Sites. The highest concentrations observed were found in two virgin profiles of Panoche soil series; nitrogen values averaged 233 and 234 mg/l in the tile zone. High nitrogen concentrations were also found in soil extracts taken from virgin profiles of the Lost Hills and Panhill series, close relatives of the Panoche series. However, low to moderate levels of nitrogen were also observed in some virgin profiles of these soils where natural leaching occurred.

Irrigated Sites. Two irrigated sites of Lethent series located in the basin rim physiographic position were nearly as high in nitrogen as some of the virgin alluvial sites mentioned above. One experimental tile system which was mentioned previously in this report had nitrate-nitrogen concentrations exceeding 2,000 mg/l. However, soil conditions at these sites were not considered representative of other known basin rim areas where tile systems have been installed. Four basin rim sites, which included one site of Rossi, one of Volta and two of the Orestimba soil series, averaged 4 mg/l, which correlated closely with tile drainage from soils in similar physiographic positions, but from different soil series.

In several profiles of the Panoche series examined in irrigated areas, nitrogen ranged from 6 to 94 mg/l and averaged about 37 mg/l in the saturation extracts. Only one irrigated site of Panhill soil was sampled; nitrogen averaged 35 mg/l.

Table 22 compares the average nitrogen for virgin soils to that of irrigated soils. The data show that nitrogen is significantly higher in virgin soils.

Alluvial Fan and Interfan Sites. Soil samples collected from virgin sites within the main course of a depositing stream are usually well leached and contain less nitrogen than soils located in interfan areas. The extent of natural leaching depends mainly upon the texture and stratigraphy of the soil, precipitation, and relative proximity to a stream or creek at one time or another. The data compiled in Table 23 show that nitrogen is much more concentrated in the soils sampled from alluvial interfan areas than from fan areas in the direct course of a depositing stream.

TABLE 22

NITROGEN IN VIRGIN AND
IRRIGATED SOIL PROFILES

Soil Series	Virgin Soils[1/]			Irrigated Soils		
	No. of Sites	NO_3-N (mg/l) Profile Range[2/]	NO_3-N (mg/l) Average[3/]	No. of Sites	NO_3-N (mg/l) Profile Range[2/]	NO_3-N (mg/l) Average[3/]
Panoche	7	1 - 234	76	11	6 - 94	37
Panhill	6	8 - 209	126	1	--	35
Lost Hills	5	4 - 206	66	1	--	3
Sorrento	1	--	32	1	--	17

1/ Virgin and dry-farmed sites.
2/ Range of concentrations between different sites.
3/ Average nitrate-nitrogen in tile zone, depth-weighted.

TABLE 23

RESIDUAL NITROGEN IN VIRGIN SOIL
PROFILES OF ALLUVIAL FAN AND INTERFAN AREAS

Soil Series	Alluvial Fan[1/]		Alluvial Interfan	
	No. of Sites	Average NO_3-N (mg/l)	No. of Sites	Average NO_3-N (mg/l)
Panoche	3	10	2	234
Panhill	1	12	6	130
Lost Hills	3	5	2	120
Sorrento	1	17	1	32
Rincon	2	8	--	--

1/ Selected in the main course of the depositing stream.

Interfan areas are those which are protected from repeated flushing action of a nearby stream by their slightly higher elevation. Interfan areas are interspersed with the many coalescing alluvial fans on the west side.

Different Geographical Sites. Soil profiles located in the northern area tended to be lower in nitrogen than were the soils investigated in the central area. Values ranged from 2 mg/l for one Rincon site to 59 mg/l at a site of Ambrose soil; both sites were dry-farmed. Drainage from three tile systems located in Ambrose soil never approached this value. More sites are needed in the northern area to evaluate the magnitudes of residual nitrogen in virgin and irrigated soil profiles.

Nitrogen in Soils and Tile Drainage

Whenever possible, comparisons were made between the nitrogen found in soils (saturation extracts and field extracts) and that of tile drains, either in the same tiled field, nearby field, or the same soil series located some distance away. However, much variability exists in soils, and soils data were somewhat limited; therefore, only a few comparisons could be made.

Saturation Extracts and Field Extracts. The most universally accepted method for determining specific ions in soil samples is the analysis of soil solutions known as the saturation extract (28). The extracts are prepared by adding distilled water to an oven-dried soil sample until a condition of saturation is reached. The leachate then is extracted by means of a suction filter device. The water content of a saturated paste generally exceeds that found in the soil under saturated field conditions because of the lower volume weight and greater porosity. The saturation percentage (SP) is expressed as grams of water per 100 grams of soil.

Soil solutions extracted from saturated soil pastes have been determined to be as near as possible to the water content which occurs under field conditions. However, the concentration of salts in tile drainage cannot be expected to be exactly the same as that in saturation extracts. As a soil approaches the permanent wilting point (PWP), the soil solution becomes much more concentrated. The PWP varies for different soils and is generally expressed as the percent of moisture in a soil on a dry-weight basis at which plants wilt and are unable to regain turgidity.

The moisture content of the soil fluctuates between the lower limit represented by PWP and the upper or wet end of the available moisture range -- field capacity (FC). FC, which is defined as the amount of moisture retained by a given soil after a period of free drainage, is approximately twice the PWP. Tests have shown that the SP over a wide textural range is equal to four times the PWP. Therefore, the salt concentration in a saturated extract is roughly one-half that of the soil solution at FC and one-fourth the concentration of the soil solution at the PWP.

Soil-Moisture Relationships. In addition to the difficulty evident in the selection of samples representative of average soil conditions from a given field and the biochemical disturbances created during soil preparation in the laboratory, certain field conditions exist which cannot be duplicated. For example, tiled fields seldom occupy areas having the homogeneity that is found in a small sample of soil. Stratigraphic and structural variability is prevalent in the soils on the west side of the Valley. Efficient tile operation is dependent upon the presence of coarse-textured material within the soil profile; therefore, certain portions of fields are not only drained at different times depending upon the portion of the field being irrigated, but also at different rates depending upon differences in soil permeability and lateral hydraulic conductivity. Vast areas of soils along the west side have been classified as having greater lateral than vertical hydraulic conductivity (29). These soil conditions were somewhat substantiated by the quantities of effluent discharged from several tile systems investigated in the study area.

Whenever tile systems are installed in soils such as those just described, the coarse-textured material (aquifers) is leached rapidly and the finer textured portions of a field are leached more slowly. The intensity of irrigation and its duration may determine to some extent the effective leaching of these fine-textured regions of a field. (These isolated conditions are seldom shown on a soils map.) These dense areas approach saturation more slowly than the coarse-textured areas during normal irrigation. If nitrate ions or other ions are present, they may not have the opportunity to solvate and drain into the shallow ground water. Therefore, soil moisture extracted directly from the field by means of porous cups may be more indicative of the actual field salinity and soil nitrate levels than saturated extracts. The number of samples collected and timing of sampling (for different periods of agricultural activity), the depths sampled and the specific textural areas sampled all play an important part in obtaining a soil sample representative of moisture and salt conditions within an entire field area. Considerable time was spent for field exploration before sites were selected for the in-field moisture sampling.

Field Comparisons. During 1966, a cooperative investigation between the Department of Water Resources, the Environmental Protection Agency (EPA) (then the Federal Water Quality Administration), and the University of California at Davis was conducted in the Firebaugh area. Soil samples were collected from several fields and samples were analyzed for nitrates and other minerals. These investigations revealed moderate concentrations of nitrogen in the saturation extracts collected from three irrigated Panoche soils. Nitrogen concentrations in the tile drainage were much higher, as shown by comparison in Table 24.

TABLE 24

NITROGEN CONCENTRATIONS IN SATURATION EXTRACTS AND DRAINAGE FROM THREE TILED FIELDS OF THE PANOCHE SERIES 1966

Field Code	Concentrations of NO_3-N (mg/l)					
	Saturation Extracts		Tile Drainage 1/			
	Profile-Range 2/	Average 3/	1966	1967	1968	1969
FBH 5056	4-22	10	50	37	49	54
FBH 4045	2-34	7	31	19	28	4/
FBH 3236	7-30	14	44	39	44	4/

1/ Weighted annual concentrations.
2/ Range of concentrations between different sites.
3/ Average nitrogen in tile zone, depth-weighted.
4/ Not sampled.

Nitrogen concentrations observed in the tile drainage during June and July, the months during which soil samples were collected, were not too different from the annual averages shown by the data for the whole year (1966). Data from subsequent investigations of tile drainage (1967-69) showed that nitrogen concentrations varied to some degree but never reached the levels observed in the saturation extracts.

Field investigations by the then FWQA showed that soil moisture extracted by "in-field" samplers contained higher nitrogen concentrations than did tile drainage, in three out of four fields studied. Soil moisture samples were obtained by means of suction devices (porous cups) installed at 1-foot increments up to 4 feet in depth at several locations within the tiled fields. The data show average nitrogen concentrations in the field moisture between 1 and 4 feet compared to the average concentrations observed during the same year for each tile system (Table 25). Field moisture samples from the surface (0 to 1 foot) contained much higher nitrogen concentrations than did the subsurface and subsoil samples. These high values were presumed to be influenced from fertilizers and were not included in the averages.

TABLE 25

NITROGEN CONCENTRATIONS IN FIELD MOISTURE AND DRAINAGE FROM FOUR TILED FIELDS 1967

Field Code	Soil Series	Soil Type	NO_3-N (mg/l): Profile Range 1/	Average NO_3-N (mg/l): Field Moisture 2/	Average NO_3-N (mg/l): Tile Drainage 3/
BFS 8003	Oxalis	Silty clay	17 - 39	25	6
FBH 5056	Panoche	Silty clay	18 - 53	33	37
DPS 1016	Panoche	Loam	16 - 284	94	28
FBH 4045	Panoche	Fine sandy loam	36 - 64	48	19

1/ Range of concentrations by depth within the field.
2/ Samples were extracted from porous cup devices within the fields.
3/ Weighted average concentrations.

From the data presented in the two foregoing tables, very little correlation seems to exist between the nitrogen concentrations in soil moisture collected from the field and that observed in tile drainage.

Nitrogen in saturation extracts of different irrigated soils (Table 21) is compared to that observed in tile drainage (1967-68 averages) from the same-named soil series (Table 26). A close correlation was found in only one out of six soil series examined. This was for the Panoche series where there was a sufficient number of samples represented in each case.

TABLE 26

NITROGEN CONCENTRATIONS IN SATURATION EXTRACTS AND TILE DRAINAGE FROM IRRIGATED SITES

Soil Series	Physiographic Position	No. of Sites	Saturation Extracts Average1/ NO_3-N (mg/l)	No. of Tile Systems	Tile Drainage Average2/ NO_3-N (mg/l)
Ambrose	Older alluvial fan	1	59	3	7
Lethent	Basin rim	2	142	2	20
Lost Hills	Older alluvial fan	1	3	3	54
Panhill	Recent alluvial fan	1	35	4	45
Panoche	Recent alluvial fan	11	37	8	38
Sorrento	Recent alluvial fan	1	17	6	11

1/ Average NO_3-N in soil from 1 to 8 feet, 1966-67.
2/ Weighted average concentrations over two years, 1967-68.

Comparisons of nitrogen concentrations of extracts and tile drainage from similar virgin soils could not be made because tile systems are rarely installed in virgin areas.

Saturation extracts of virgin Panoche and related soils (Panhill and Lost Hills, Table 21) of one area averaged 86 mg/l in the tile zone. Tile drainage from another area of Panoche soils, farmed but not previously tiled, averaged 44 mg/l, considerably less than that found in the saturation extracts.

Future Tile Drainage

Tile drainage system installation is expected to continue in the northern area (Byron-Westley and Westley-Gustine). Tentative plans have been made for installations south of the town of Tracy and near the towns of Patterson and Newman. Tile systems have been installed nearly every year in the Gustine-Mendota area and are expected to continue, especially since the introduction of plastic conduit. In the Tulare Lake area, the number of tile drainage systems has not increased since 1966. Tile drainage discharges for future periods from these and other areas have been predicted by the San Joaquin Valley Drainage Advisory Group (30).

San Luis Unit Service Area

One of the most important areas to consider from the standpoint of future drainage is the Federal San Luis Unit Service Area. The U. S. Bureau of Reclamation estimates that the annual agricultural wastewater disposal requirement (30) will reach 155,000 acre-feet in 50 years and is expected to exceed this by 2035. This amounts to better than one-third the total volume predicted from the entire San Joaquin Valley for the same period.

An important consideration, aside from the quantity of drainage from this area, is the expected nitrogen content. If the drainage is high in nitrogen, it could raise the predicted levels higher than anticipated and could also affect the seasonal variability of nutrient concentrations. Soils within the SLUSA are among those already mentioned: Panoche, Panhill, Lost Hills, Oxalis, Levis, and Lethent. However, according to the tile drainage plans proposed by Westlands Water District, the largest amount of the 300,000 acres that are to be drained will be located along the eastern portion of the area near the trough, which is represented mostly by the Oxalis soil series of the basin rim physiographic position. The Lethent and Levis series also occupy sizable acreages in the area. There also may be some influence from Panoche soils where tile system laterals extend into the lower alluvial fan position.

According to findings mentioned in previous sections of this report, tile drainage from basin rim and basin position soils in the nearby Gustine-Mendota area was never found to be high in nitrogen. Moderate concentrations were observed in a few tile drains where soils of recent alluvial fans merge with soils of the basin rim position. Therefore, tile drainage data would seem to indicate that nitrogen concentrations from the basin rim soils in the San Luis Unit Service Area would be lower than 33 mg/l, the 1967-68 average for the Gustine-Mendota area. This area consists mostly of soils occupying recent alluvial fans.

However, in some cases basin rim soils appear to contain high nitrates. Investigations by the Department have shown that residual nitrogen in soils of the basin rim was quite low, except for two sites of Lethent soils located in the north end of the SLUSA. The USBR found sites of high nitrate-nitrogen at two sites of west side soils during collection of soil material for its lysimeter studies (22). The initial leachate collected from the lysimeters filled with Oxalis and Panoche soils ranged respectively from 564 to 4,515 mg/l nitrate-nitrogen. These high concentrations were attributed to disturbances and aeration resulting in rapid nitrification of organic matter. After leaching, the nitrogen concentrations reached static levels of 25 mg/l for Panoche and 226 mg/l for Oxalis, which were very close to the concentrations observed in the initial soil-water extracts taken at the time the soil was removed from the field. Further investigations of soil nitrogen by USBR in the SLUSA revealed variable concentrations of nitrogen in irrigated soil profiles. Thirteen sites were sampled in four transects across the Valley; five holes were bored at each site to depths of 40 feet in some cases. The range and average nitrogen concentration for the tile zone (3 to 10 feet) at each site are given in Table 27.

TABLE 27

NITRATE-NITROGEN CONCENTRATIONS IN IRRIGATED WEST SIDE SOILS INVESTIGATED BY USBR

Site No.	Soil Series and Type	Avg. Sat. %1/	Range of NO_3-N in Soil Profiles (mg/l)2/	Avg. NO_3-N in Soil Profiles (mg/l)
1	Oxalis silty clay	49	3 - 99	19.0
2	Lethent silty clay	48	0 - 27	4.0
3	Panoche clay loam	43	0 - 18	5.0
4	Panoche silty clay	50	0 - 49	16.0
5	Oxalis clay	67	0 - 68	24.0
6	Lethent clay3/	60	2 - 71	9.0
7	Levis silty clay	78	1 - 22	8.0
8	Oxalis silty clay	87	1 - 482	206.0
9	Panoche silty clay	46	2 - 129	18.0
10	Lost Hills silty clay	51	4 - 228	109.0
11	Panoche clay loam	36	4 - 195	35.0
12	Panoche silty clay	64	1 - 125	20.0
13	Oxalis silty clay	68	0 - 38	5.0

1/ Average saturation percentage.
2/ Range of NO_3-N by depth between sites
3/ Soil was sampled to 5 feet only.

Nitrate values in soil-water extracts were averaged, converted to nitrogen, and divided by the average saturation percentage to bring the values close to those of saturation extracts. The highest concentrations were found at one site of the Oxalis soil series; nitrogen averaged 206 mg/l in the tile zone. All other Oxalis sites had low to moderate concentrations. The next highest concentration was found at a site of Lost Hills series; nitrogen levels averaged 109 mg/l. Only moderate concentrations of nitrogen were found in the Panoche series; average concentrations ranged from 5 to 35 mg/l at the five sites sampled. These soil nitrogen values were slightly lower than those found in saturation extracts of irrigated Panoche soils by the Department.

If the sites sampled by USBR are representative of the soils in the SLUSA, then future drainage from this area could possibly be higher in nitrogen than from the Gustine-Mendota area. All the Oxalis sites sampled from that area averaged 64 mg/l, a value that is much higher than the values indicated in tile drainage or soil samples collected from the basin rim soils of the Gustine-Mendota area. If the 13 sites investigated by USBR are weighted by the number of borings at each site, the average is 37 mg/l (Table 28), close to the two-year average from tile systems in the Gustine-Mendota area.

TABLE 28

NITRATE-NITROGEN CONCENTRATIONS FOR DIFFERENT SOIL SERIES INVESTIGATED BY USBR

Soil Series	No. of Borings	NO_3-N (mg/l) Profile Range 1/	Average
Lost Hills	5	4 - 228	109
Oxalis	20	0 - 482	64
Panoche	25	0 - 195	19
Levis	5	1 - 22	8
Lethent	5	4 - 9	6
Weighted Grand Average 2/			37

1/ Maximum and minimum observed within all profiles sampled.

2/ Weighted by number of borings.

Residual Nitrogen in Parent Materials of West Side Soils

Genesis and Morphology. The composition of parent rock* is an important factor in determining soil characteristics in an area of arid climatic conditions, such as the west side of the San Joaquin Valley. The rocks of the Diablo Range, from which all the soils in the study area except the basin soils of the area have been derived, are classed geologically as a series of sandstones, shales, and conglomerates of Cretaceous and earliest Tertiary (Eocene) age (6). It is from these formations that parent materials of west side soils have developed.

Soils associated with certain drainage ways of the coastal foothills contain varying quantities of salts, such as gypsum, calcium carbonate, and sodium carbonate. Only in the last few years has interest in nitrates in subsurface and ground waters developed. Consequently, data on quantity and quality of nitrates are scarce. As related previously in this report, several instances of high nitrates have been found in certain alluvial soils which cannot be accounted for by fertilization. Existing concentrations in these profiles vary according to the extent of leaching caused either by natural streams or by recent irrigation.

Nitrogen Concentrations in Parent Materials

To better understand the persistence of native or residual nitrogen, one must realize that these soil profiles have developed in a relatively dry environment (6 to 8 inches total precipitation per year). Flash storms produced many mud flows; intermittent streamflow, which carried heavy loads of fine material, subsequently deposited this material. Periods of flooding were followed by periods of rapid evaporation, which allowed little time for deep percolation.

This developmental process was quite clear to Agricultural Research Service investigators during their deep boring studies (15). Findings at two of these plots in Panoche soils promoted investigations of parent materials in old drainage ways of the Diablo Range, which were presumed to be the source of the alluvium. Samples were collected from several sites in three main arroyos: Ciervo, Hondo, and

*Parent materials are defined (7) as the unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soils is developed under pedogenic processes.

Big Panoche. They were collected from stratified zones (hillsides, gullies, and ridges), mud flows, streams and creeks. Average nitrate-nitrogen was determined for samples collected in similar zones and is presented in Table 29.

TABLE 29

SUMMARY OF NITRATE-NITROGEN CONCENTRATIONS FOUND IN PARENT MATERIALS[1/] OF WEST SIDE ALLUVIAL FAN SOILS

Sites Sampled	NO_3-N (mg/l)[2/] Ranges	Average
Surface, small delta	420.0 -1,820.0	1,120.0
Subsurface, small delta	1,134.0 -3,360.0	2,240.0
Miscellaneous strata	1.4 -1,890.0	210.0
Mud flows (clods)	0.3 -5,600.0	294.0
Mud puddles (water)	0.4 - 3.9	1.5
Streams (water)	0.07- 3.9	0.7
Streambeds (dry)	12.4 - 60.0	35.0
Creeks (Cantua, Ciervo, Big Panoche)	0.14- 4.2	2.6
Arroyos (face, sides, depths)	0.4 -1,169.0	137.2

1/ Tertiary marine sediments at the Coast Range.
2/ Concentrations in 1:1 soil-water extracts.

The data show that extremely high nitrates do exist in various parent materials. Although a great variability exists among the sites, these data do provide a sound basis for determining the source of nitrates that occur in certain alluvial fan soils. The data also explain the presence of high nitrogen in tile drainage from these same certain soils.

SECTION VI

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SECTION VII

PUBLICATIONS

SAN JOAQUIN PROJECT, FIREBAUGH, CALIFORNIA

1968

"Is Treatment of Agricultural Waste Water Possible?"
Louis A. Beck and Percy P. St. Amant, Jr. Presented at Fourth International Water Quality Symposium, San Francisco, California, August 14, 1968; published in the proceedings of the meeting.

1969

"Biological Denitrification of Wastewaters by Addition of Organic Materials"
Perry L. McCarty, Louis A. Beck, and Percy P. St. Amant, Jr. Presented at the 24th Annual Purdue Industrial Waste Conference, Purdue University, Lafayette, Indiana. May 6, 1969.

"Comparison of Nitrate Removal Methods"
Louis A. Beck, Percy P. St. Amant, Jr., and Thomas A. Tamblyn. Presented at Water Pollution Control Federation Meeting, Dallas, Texas. October 9, 1969.

"Effect of Surface/Volume Relationship, CO_2 Addition, Aeration, and Mixing on Nitrate Utilization by *Scenedesmus* Cultures in Subsurface Agricultural Waste Waters"
James F. Arthur and Randall L. Brown. For publication in Eutrophication Report by University of California, Berkeley, California. August 1969.

"Nitrate Removal Studies at the Interagency Agricultural Wastewater Treatment Center, Firebaugh, California"
Percy P. St. Amant, Jr., and Louis A. Beck. Presented at 1969 Conference, California Water Pollution Control Association, Anaheim, California, and published in the proceedings of the meeting. May 9, 1969.

"Research on Methods of Removing Excess Plant Nutrients from Water"
Percy P. St. Amant, Jr., and Louis A. Beck. Presented at 158th National Meeting and Chemical Exposition, American Chemical Society, New York, New York. September 8, 1969.

1969

"The Anaerobic Filter for the Denitrification of Agricultural Subsurface Drainage"
Thomas A. Tamblyn, and Bryan R. Sword. Presented at the 24th Annual Purdue Industrial Waste Conference, Lafayette, Indiana. May 5-8, 1969.

"Treatment of High Nitrate Waters"
Percy P. St. Amant, Jr., and Perry L. McCarty. Presented at Annual Conference, American Water Works Association, San Diego, California. May 21, 1969. American Water Works Association Journal. Vol. 61. No. 12. December 1969. pp. 659-662.

"The Effects of Nitrogen Removal on the Algal Growth Potential of San Joaquin Valley Agricultural Tile Drainage Effluents"
Randall L. Brown, Richard C. Bain, Jr., and Milton G. Tunzi. Presented at the American Geophysical Union National Fall Meeting, Hydrology Section, San Francisco, California, December 15-18, 1969.

"Harvesting of Algae Grown in Agricultural Wastewaters"
Bruce A. Butterfield, and James R. Jones. Presented at the American Geophysical Union National Fall Meeting, Hydrology Section, San Francisco, California, December 15-18, 1969.

"Monitoring Nutrients and Pesticides in Subsurface Agricultural Drainage"
Lawrence R. Glandon, Jr., and Louis A. Beck. Presented at the American Geophysical Union National Fall Meeting San Francisco, California, December 16, 1969.

"Combined Nutrient Removal and Transport System for Tile Drainage from the San Joaquin Valley"
Joel C. Goldman, James F. Arthur, William J. Oswald, and Louis A. Beck. Presented at the American Geophysical Union National Fall Meeting, Hydrology Section, San Francisco, California, December 15-18, 1969.

"Desalination of Irrigation Return Waters"
Bryan R. Sword. Presented at the American Geophysical Union National Fall Meeting, Hydrology Section, San Francisco, California, December 15-18, 1969.

"Algal Nutrient Responses in Agricultural Wastewater"
James F. Arthur, Randall L. Brown, Bruce A. Butterfield, and Joel C. Goldman. Presented at the American Geophysical Union National Fall Meeting, Hydrology Section, San Francisco, California, December 15-18, 1969.

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27 *Abstract*

Tile drainage systems of the San Joaquin Valley were monitored for nutrients (nitrogen and phosphorus) to determine the algal growth potential (AGP) of the waste, and the degree of treatment required for removal of AGP. The objectives were to determine: (1) the average nutrient concentrations in tile drainage, (2) the magnitudes of annual, areal and seasonal variability of nutrients and discharges, (3) if a possible correlation exists between nutrients and agricultural practices, and (4) if existing soil conditions influence nutrient concentrations and flows.

Average discharges and nutrient concentrations were calculated for different years, months and areas of interest (valleywide, major tiled areas, physiographic positions and soils). Average nutrient concentrations in the composited drainage from the Valley were found to be 19.3 mg/l for nitrogen (NO_3-N) and 0.09 mg/l for phosphorus (PO_4-P); average discharge was 1.4 ac-ft/ac/yr. Nutrient levels in the composited drainage did not change appreciably with time. Variability of nutrients was observed for different seasons; a twofold decrease in nutrients was attributed to dilution by irrigation and denitrification. N was three times more concentrated in drainage from one out of four major tiled areas investigated. The high N levels were attributed more to indigenous concentrations in certain alluvial fan soils and their parent materials than fertilization. Low N levels found in drainage from basin soils were believed caused by denitrification. P was seven times higher in the drainage from the southernmost area than the other areas investigated. These extraordinarily high levels (0.69 mg/l) were attributed to indigenous concentrations in certain soils made available by anaerobic soil conditions. High discharge in the northernmost area (2.3 ac-ft/ac) was believed to be caused by rapid lateral hydraulic conductivity and surrounding irrigation influence.

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